INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

(IESS)

UNIVERSITY OF GHANA, LEGON

ASSESSMENT OF SUITABILITY OF SLUDGE AND WASTEWATER QUALITY IN WASTE STABILISATION POND SYSTEM IN ACCRA-GHANA FOR AGRICULTURE PURPOSES

BY

EMMANUEL ADU-OFORI

(10599129)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF

MPHIL ENVIRONMENTAL SCIENCE Degree’’.

JULY, 2019

DECLARATION

I do declare that, except for the references to other people's work which have been cited, this work submitted as a project to the Institute for Environment and Sanitation Studies, University of Ghana, for the degree of MPhil, in Environmental Science is the result of my own investigation and has not been presented for any degree. This thesis is hereby submitted for examination with the approval of my supervisors.

.... 29/10/2020

EMMANUEL ADU-OFORI Date

(CANDIDATE)

29/10/2020

Dr. Daniel Nukpezah Date
(Principal Supervisor)

29/10/2020

----------- ---------- -------------------------

Dr.Samuel Senyo Koranteng Date
(Co- Supervisor)

DEDICATION

This work is first of all dedicated to the God almighty. Also, to my lovely wife Juliana Adu-Ofori (Mrs.) and children for their affection and support.

ACKNOWLEDGEMENTS

I would first like to express my profound gratitude to my supervisors, Dr. Daniel Nukepzah and Dr. Samuel Senyo Koranteng for their professional guidance, valuable advice, encouragement and strong support. Their contribution as a team and as individual has been the pillar in the present study. My gratitude also goes to Dr. Isaac O. A Hodgson immediate past Head of Environmental Chemistry and Sanitation Engineering Division of Water Research Institute, under whose diligent supervision, this study has been successfully completed. I am also grateful to Dr. Anthony Yaw Karikari, Head of Environmental Chemistry and Sanitation Engineering Division of Water Research Institute for allowing me to use their laboratories for my analysis and everything else. I would also like to express my gratitude to Mr. Serapis Asiedu Appiah, Mr. Daniel Amoah, Mr. Michael Afram Danquah and Mr. Lawrence Yawson of the Chemistry Division who helped with my analysis in the laboratory. I also thank Mr. Borbor Selorm of the Microbiology Division. My gratitude is also extended to Mr. Emmanuel Nartey the technical officer in charge of the Accra sewage improvement project (ASIP) treatment plant who supported me throughout my sampling.

Lastly, my profound thanks go to Jefferson Lloyd Obeng, Atikatu Mohamadu service personnel of the Chemistry Division, the staff and lectures of Institute for Environment and Sanitation Studies, University Of Ghana, and my course mates for their encouragement and valuable contribution towards the successful completion of this study.

Glossary

WSP-Waste stabilisation pond

AAS- Atomic Absorption Spectrophotometer

EU- European Union

FAO- Food and Agriculture Organization

LSD- Least Significant Difference

SAR-Sodium absorption ratio

mg- milligrams

ppm- parts per million

SD- Standard Deviation

Temp- Temperature

USEPA- United States Environmental Protection Agency

WHO- World Health Organization

EPAG- Environmental Protection Agency Ghana

Blackwater – Wastewater stream originating from the toilet: urine, faeces, toilet paper

BOD – Biochemical Oxygen Demand

COD – Chemical Oxygen Demand

Digestate –by-product from biogas production

Manure – Animal feces

Greywater – Wastewater originating from e.g. washing, showers, baths

ASTP – Accra sewage treatment plant

CSIR- Council for scientific and Industrial Research

WRI- Water Research Institute

WRC-Water Resources Commission

IWFSM- Integrated Wastewater and Faecal Sludge Management

ABSTRACT

The objective of this study is to analyse the physico-chemical and bacteriological parameters, evaluate the performance of domestic sewage ponds at Accra sewage treatment plant at Legon. The aim is to assess the suitability of the final effluent for irrigation and the quality of sludge for agriculture use. A total of 36 wastewater samples and forty-eighty (48) sludge samples were therefore taken for six (6) consecutive months from the sedimentation tank (inlet) and maturation pond (outlet) of the Legon sewage treatment plant at the University of Ghana Legon campus. The samples were preserved on ice and transported to the CSIR Water Research Institute for laboratory analysis. All the methods of analyses carried out were done according to procedures in the Standard Methods for the Examination of Water and Wastewater (APHA, 2012, 22nd Edition). The wastewater quality parameters used to assess the treatment performance of the WSP were total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, phosphate and *E. coli*. The results of the laboratory analysis showed that the WSP achieved about 82.2, % 86.8, % 82.8%, 85.2%, 58.7% and 99.9% removal of TSS, BOD, COD, ammonia-nitrogen, phosphate-phosphorus and *E*.coli respectively. Even though removal efficiency of *E.coli* was high, it recorded a value of 153×10^3 cfu /100ml which could not meet the Ghana EPA acceptable standard of 10 cfu/100ml.At $p \leq 0.05$, there was a significant difference in the levels of Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia-Nitrogen, Nitrate-Nitrogen, Phosphate, and *E.coli* between influent and effluent samples.

The sludge as an organic matter can exert significant influence on the physical, chemical and biological properties of soils. The heavy metals levels were generally acceptable when compared with the Limits for metals brought to agriculture land by sewage sludge in South Africa (SFS, 1998:944; Water Research Commission, 1997. Zinc in stream-1 anaerobic pond ranged from 12.3 to 80.0mg/kg with a mean of 64.7mg/kg. Similarly Zinc in stream-2 anaerobic pond ranged from 62.8 to 82.3 mg/kg with a mean of 69.9 mg/kg.

The results show that total nitrogen, total phosphorus and total potassium levels in the sludge are also generally satisfactory to produce organic compost (manure). Total nitrogen in stream-1 anaerobic pond ranged from 16800 to 19000 mg/kg with a mean of 17800 mg/kg. Total phosphorus ranged from 350 to 410 mg/kg with a mean of 380 mg/kg and total potassium 206 to 210 mg/kg with a mean of 210 mg/kg. There was no significant difference in the levels of heavy metals and the nutrients levels between the stream-1 and stream-2 ponds of the sludge quality at $p \geq 0.05$.

The sludge which accumulates in the Legon sewage treatment plant can be used as a soil improver without posing any environmental hazards. It can be used in agricultural practice in order to maintain and improve soil fertility and crop yield.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

A survey of wastewater treatment procedures shows that the Waste Stabilization Pond systems (WSP) is considered the best suitable wastewater treatment which will produce an effluent, meeting the required biological and physico-chemical quality standards both at low budget and with marginal operational and maintenance requirements (Ghazy *et al*., 2008).

There are many forms of wastewater treatment used worldwide, such as activated sludge, trickling filter and waste stabilization pond systems. In the developing countries stabilization pond are usually used for metropolitan sewage purification, because of its cost effectiveness and high possibility of removing different pollutants (Ghazy *et al*., 2008).

Stabilization ponds are made to attain different forms of treatment up to three stages in series, reliant on the organic strength of the input waste and effluent quality (Ghazy *et al.,* 2008). Usually, classical stabilization ponds consist of an anaerobic pond, followed by primary or secondary facultative ponds and maturation pond for reduction of pathogen and nutrients. As a result of its economic benefits and low operational requirement, the treatment method has been generally used for minor rural populations (Ghazy et al., 2008).

In Ghana and specifically in the warm and equatorial counties, a lack of wastewater treatment systems is witnessed in countryside communities and city centres. There is therefore a great need for wastewater treatment systems to avoid the health risk problems in these communities. According to Mara (2004), water that has been used by the public which contains all the materials made up of faeces and urine together with the water used for flushing toilets, and sullage, which is grey water is considered as domestic wastewater.

Some of the possible adverse effects of wastewater on receiving water bodies include loss of fish life, high levels of sludge deposition, formation of putrefying environments and stenches released from anaerobic reactions that may arise at the bottom of the receiving water body, increased water treatment cost, eutrophication and ultimate loss of water resources Mara and Oragui (1981).

Wastewaters with high levels of faecal coliforms have the potential of causing health problems to the people who may come in direct contact with the receiving water body. Waste stabilization ponds are becoming popular for treating wastewater in warm and semi warm regions due the abundant sunlight and high ambient temperatures.

In Ghana the most predominant treatment system is the stabilization ponds, which are found in almost all the regional capital cities, as well as the trickling filter and activated sludge. The waste stabilisation ponds constructed in some of the cities and communities in Ghana have performed very well. Akuse, Akosombo, Kumasi and University of Ghana Accra are some of the places where the stabilisation ponds can be found.

1.2 Statement of the Problem

Much research that has been conducted to evaluate the performance of Waste Stabilization Ponds (WSPs) has mainly focused on the effluent quality that is discharged into our water bodies. To construct wastewater stabilization ponds (WSPs), the sludge management, the understanding of build-up rates and sludge characteristics is very essential. It will be useful to establish the effluent quality, sludge quality characteristics, and sludge accumulation rates in the various ponds constructed by University of Ghana and Accra Metropolitan Assembly in order to evaluate the efficiency of the treatment plant and if possible, use the effluent for irrigation of crops. According to Pena and Mara (2000), unnecessary sludge build-up affects the hydraulic performance by reducing the effective volume, increasing short circuiting and feedback loads and therefore reducing the treatment efficiency. Concerns for domestic wastewater management most especially treatment of wastewater in Ghana is not a priority to the citizens and city authorities. Waste Stabilization Ponds (WSP) are constructed to make the public sewage environmentally friendly before discharged into the environment (land or water bodies), in order to reduce the environmental and health effects of the wastewater, and to make the wastewater fit for reuse (agricultural and aqua-cultural uses, municipal and industrial uses and the sludge for organic manure for agricultural compost). The health importance of wastewater recycle can only be evaluated by an epidemiological research of the specific treatment process. These studies are methodologically challenging, and there have been only a few well-designed epidemiological researches on human waste recycle. Shuval *et al*., (1986) reviewed all accessible epidemiological research on wastewater irrigation and concluded that, crop irrigation with untreated wastewater causes significant excess intestinal nematodes, mostly hook worm's infections in crop consumers and field workers. However, irrigation with effectively treated wastewater does not lead to excess intestinal nematode infection in crop consumers and field workers. Cholera and typhoid can be effectively transmitted by irrigation of vegetable crops with untreated wastewater (Clescerl *et al*., 2008). Therefore, effective treatment of sewage must decrease the level of organic compounds substantially, in addition to eliminating pathogens, toxic materials, and other pollutants (Nester *et al*., 2004). Organic compounds like PAH and PCB have acceptable standard of 6 mg/kg and 0.8 mg/kg respectively in most of the EU countries (EU 2000). Hence, this study is to evaluate the efficiency of the wastewater treatment plant and the pathogen loads of the treated water and the quality of sludge that accumulates in Legon sewage treatment plant WSP at the university of Ghana campus. These studies will lay emphasis on sludge quality and its usefulness.

1.3 Research Questions

The research seeks to answer the following questions:

•What is the physico-chemical and bacteriological quality of the influent and effluent with reference to the performance efficiency of the treatment plant?

•What is the physico-chemical and bacteriological quality of the effluent for irrigational purposes?

•What is the quality of the sludge for organic compost (manure?)

1.4 Research Objective

The main objective of this research is to assess the performance of domestic sewage treatment plant at the University of Ghana campus.

Specific Objectives

- To assess the performance efficiency of the treatment plant with respect to physico-chemical and bacteriological qualities of the influent and effluent discharges.
- To analyse the physiochemical effluent quality of the treated effluent for irrigational purposes.
- To determine the quality characteristics of the sludge for organic compost (manure).

1.5 Organization of research work

The study on the assessment of suitability of sludge and wastewater quality characteristics in waste stabilisation pond system in Accra-Ghana for agricultural purposes comprises five chapters and a reference section. Chapter one is “Introduction”. Chapter two is “Literature Review”. Chapter three is “Materials and Methods”. This chapter classifies the work elements of the study and brings forth the method followed to perform the analyses on the identified work elements.

Chapter four is “Results and Discussion” and “Conclusion/Recommendation” is presented in chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

2.1 Waste Stabilization Pond Systems

The knowledge in waste stabilization pond systems (WSPs) provides essential benefits and exciting potentials when observed in the view of maintainable energy and carbon management. WSP systems are considered as having important benefits due to simple construction; low (or zero) working energy supplies; and the possibility for bio-energy generation through solar-powered aerobic treatment and sterilisation; moreover, energy may be cost-effectively produced as biogas from anaerobic ponds Craggs, *et al* (1999). According to De-Garie, *et al* (2000) conventional WSP needs little or no electrical energy for aerobic treatment as a result of algal photosynthesis. The solar energy facilitates efficient purification of wastewaters in WSP without the need for any chemicals or electricity consumption and their related CO_2 emissions.

Waste Stabilization Ponds systems are man-made earthen basins having low-cost, low-maintenance, extremely effective, highly sustainable and entirely natural. The source of energy they use is direct sunlight energy, this helps in reducing expenditure on electricity. Land availability is crucial in development of WSP than conventional electromechanical treatment procedures such as activated sludge.

Each type of waste stabilization ponds (WSPs) carries out a unique purpose. Anaerobic and facultative ponds are designed for BOD removal, while maturation ponds are designed to reduce faecal pathogens. Preceding the treatment in the WSPs, the wastewater is subjected to primary treatment (screening and grit removal) to remove large and heavy solids (Hammer & Hammer, 2014). Essentially, primary treatment is carried out in anaerobic ponds, secondary treatment in facultative ponds, and tertiary treatment in maturation ponds. The removal of organic matter (BOD) both soluble and suspended, Vibrio cholerae and helminth eggs occurs in the anaerobic and facultative ponds while maturation ponds remove faecal bacteria and nutrients (nitrogen and phosphorus). The treatment is attained through natural sterilisation mechanisms (Pearson *et al*., 1995).

Anaerobic ponds are normally 2-5m deep. They are the smallest units in the series and size according to their volumetric organic loading (100 to 350 g BOD_5/m^3 day) depending on the design temperature.

There is no dissolved oxygen present and the redox potential is negative. Anaerobic ponds work extremely well in warm climates: around 60% BOD_5 removal at 20°C and over 70 % at 25°C can be achieved in a properly designed pond.

Facultative ponds are usually 1-2 m deep and are geometrically designed to have high length-to-width ratio (up to 10:1) to simulate a plug flow regime and it follows anaerobic ponds in a WSP system (Mara *et al*, 1992).

The algae production by photosynthetic activity results in a diurnal variation of dissolved oxygen (DO) concentration and pH. Dissolved Oxygen concentration can rise to more than 20 mg/l (i.e., highly supersaturated conditions) and pH to more than 9.4 (these are both important factors in the removal of faecal bacteria and viruses; Curtis *et al*., 1992). According to Mara *et al.*, (1992) maturation ponds, which follows the facultative ponds are usually 1 -1.5m deep and are geometrically designed to have a high length-to-width ratio (up to 10:1) to simulate a hydraulic plug flow regime. The main function of maturation pond is to remove defecated pathogens to enable the practice of unrestricted crop irrigation (WHO, 1989).

2.2 Sludge Management

Sludge management is an integral part in the efficient functioning and treatment within WSP. The accumulation of sludge can influence performance by altering the ponds hydraulics due to a reduction in the pond’s operative capacity and variations to the bottom surface (Pena & Mara 2000). Periodic sludge removal is required to maintain a ponds ability to effectively treat the entering wastewater. However, the cost of desludging operations is significant, making the frequency of removal a key factor in the long-term sustainability of the WSP. Reported sludge build-up rates range from 0.021 m^3/person/year up to 0.148 m^3/person/year (Pena & Mara, 2000; Abis & Mara, 2003; Picot *et al*., 2005). For ponds with average temperatures exceeding 20°C, using a value of 0.04 m^3/person/year is suggested (Nelson et al. 2004). A study of 19 Waste Water Treatment Plant in South France concluded the average cost for desludging ranged from 38 €/m^3 to 62 €/m^3 depending on whether the pond is drained prior to desludging (Picot *et al*. 2005).

The population of Western Australia is approximately 2.4 million (ABS 2012), putting the value of desludging at $5 Million per year for Western Australia alone. With wastewater managers under ever increasing budget pressures, identifying the ponds with the highest desludging priority is critical to achieving maximum benefit at minimum cost.

Wastewater managers monitor sludge levels in WSP in order to estimate efficiency and predict when a pond may require desludging. Sludge height measurement has traditionally been performed using either the white towel test or the sludge judge method. The white towel test, described by Mara (2004) involves dipping a white towel into the pond and the sludge depth is estimated from the markings on the towel. The sludge judge method uses a transparent tube, open at each end, dipped to the bottom of the pond and then sealed at the top. When the tube is removed from the pond, the contents remain inside and the sludge height can be determined. The sludge height measurement methods described are time consuming, pose health and safety risks and the accuracy of the measurement itself is subjective. In light of these issues, recent theses by Morgan (2010) and Coggins (2011), worked towards providing the industry with a new sludge height measuring tool. A remotely operated vehicle (ROV) fitted with a sonar device was trialled and results compared to manual measurements.

The comparison of sludge heights collected from sludge judge surveys and those obtained from sonar measured heights showed significant and high correlation ($R^2 = 0.98$) (Coggins 2011).

2.3 WSP sludge as a soil improver

Waste stabilisation ponds sludge is another product that can be used as fertilizer. It improves the properties of the soil in terms of structure, humus content, and water holding and transmission capacity. The use of sludge in agriculture contributes to recycling of nutrients and organic matter to the soil. Furthermore, sludge is also generally a low-cost alternative in comparison to other fertilizers (Levlin *et al.*, 2001; EPA, 1999; Sommers, 1977; Korentajer, 1991).

However, there are also some challenges related to the use of sludge in agriculture. According to (Tervahautaa *et al.*, 2014; Levlin *et al.*, 2001; Wang *et al.*, 1999) heavy metals and hazardous compounds in sludge can accumulate in the crops and be transferred to humans, the acceptance of spreading sewage-based fertilizer on farmland is not total. According to (Sanin *et al.*, 2011 Korentajer, 1991) the nutrient value is another challenge when using sludge as fertilizer. Sludge is considered as a low-grade fertilizer in comparison to for example artificial fertilizers, meaning that a larger amount of sludge must be spread to achieve the same required supply of nutrients. Also, sludge contains about 80-90% of water which makes its transportation to farmlands difficult. The essence of this study is to determine the levels of the nutrients and the heavy metal in the sludge and if it can be used for organic compost which implies the sludge will not be used in its raw state.

2.4 Regulatory framework

The local government authorities such as the Metropolitan, Municipal and District assemblies have a major role to play to ensure a policy and regulatory environment that enables sustainable planning and management for Integrated Wastewater and Faecal Sludge Management (IWFSM) towards an improved and environmental health. At the national level, there are several key acts, rules and standards like the Local Government Act (Act 462), Community Water and Sanitation Agency Act 1998, National Environment Sanitation and Action Plan (NESSAP) 2010, Strategic Environment Sanitation Investment Plan (SESIP 2012), Environmental Protection Agency (EPA) Act, 1994 (Act 490) In absence of any specific legal provisions related to wastewater and faecal sludge management, the MMDAs can be guided by CSIR, NSA and MoSWR to formulate their by-laws and rules for management of wastewater and faecal sludge in their domain. In addition, the Ministry of Local Government and Rural Development would need to review the building regulations to ensure proper construction of adequate on-site sanitation facilities, which in turn need to be disseminated to the construction industry and local masons. The by-laws and rules should address design, construction, operation and maintenance of sanitation systems along the entire sanitation value chain: methods of approval of building plans, or retro-fitting existing installations, tariffs for sanitation management, penalty clause for violation of rules, laws, regulations, issuance of permit/license to private operators providing services.

2.5 Limits and regulations of sludge use in agriculture

There are several different limits and guidelines around the world that regulates how the quality of the sludge should be in order for it to be used as fertilizer on farmland. For the moment, there is no legislation or guidelines found regulating the sludge quality for use in agricultural purposes in Ghana. Guidelines and regulations from the European Union, South Africa and Sweden have though been compared.

The agricultural use of sludge within The European Union is regulated by the EG-directive 86/278/EEG and can be seen in Table 1. Since this regulation is almost 30 years old many member countries in the EU have nowadays their own legislation. The EG-directive 86/278/EEG is about to be revised (European Commission, 2015).

The agricultural use of sludge in South Africa is regulated according to the guide "Permissible Utilization and Disposal of Sewage Sludge, Edition 1" from 1997 (Snyman *et al*., 2000). The guide aims to assist and guide organizations involved in sludge treatment to promote safe handling, disposal and utilization of sewage sludge. According to the guide, sewage sludge is classified within four types: A, B, C and D, where D can be used as fertilizer and has the highest hygienic quality and highest requirements on heavy metal contents in sludge (Water Research Commission, 1997).

Limits for metals brought to agriculture land by sewage sludge in Sweden, EU and South Africa (EG, 1986/278/EEG; SFS, 1998:944; Water Research Commission, 1997)

Table 1: Limits for metals brought to agriculture land by sewage sludge

Parameter (mg/kg)	Limits Sweden	Limits EU	Limits South Africa
As	-	-	15
Cd	2	20-40	15.7
Co	-	-	100
Cr	100	1000-1500	1750
Cu	600	1000-1750	50.5
Ni	50	300-400	200
Pb	100	750-1200	50.5
Zn	800	2500-4000	353.5

2.6 Characteristics of Sludge

According to (Snyman & Van der Waals, 2004; Emongor & Ramolemana, 2004) Nitrogen, phosphorous and potassium are nutrients contained in Sewage sludge, and trace nutrients (e.g. sulphur and sodium). Also included are metals (e.g. nickel, zinc, copper and lead) and various forms of organic substances, pharmaceuticals and miscellaneous compounds. The characteristics of the raw wastewater entering the treatment plant influences the quality of sewage sludge depending on the processes at the plant and other parameters like nitrogen, phosphorous and potassium which are important for the sludge production (Snyman & Van der Waals, 2004; Bresters *et al.*, 1997).

2.7 Effluent Quality

Effluent quality is used to define the physical, chemical and biological characteristics of waste water generally in respect to its appropriateness for various uses. These characteristics are often influenced by substances which dissolve or suspend in waste water. Thus, the quality of waste water is affected by a wide range of natural, industrial and human effects. Human activities impact waste water quality directly and indirectly from particulate, dissolved, and volatile material sources which may ultimately enter water body. The quality of wastewater therefore, is closely associated to wastewater reuse because there are various measures for wastewater quality (Chapman, 1996). The wastewater quality characteristics would be divided into two main headings:

2.8 Physico-Chemical Characteristics

There are several physico-chemical characteristics used in effluent quality determination. Selected characteristics used for the study were: temperature, pH, total suspended solids, nitrate nitrogen, ammonia-nitrogen phosphorus, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand and heavy metals (Chapman, 1996).

2.8.1 Temperature

Temperature affects the rate of chemical and biochemical reactions. It influences the rate at which algae and aquatic plants photosynthesize, and how pollutants interrelate with water. Temperature also influences the solubility of dissolved oxygen and other materials in water (Tchobanoglous *et al*., 2003; Drinan & Whiting, 2001; Chapman, 1996). WSPs are exposed to the atmosphere all year round, the changes in the seasons or weather conditions could influence the quality of the treated effluent and the performance. The diurnal variation has been shown to influence the quality of the final effluent (Hodgson, 2003).

2.8.2 pH

pH is a degree of the hydrogen ion concentration in a medium. It influences the degree of ionization of toxic substances such as ammonia and it is closely linked to biological productivity. Although, pH tolerance levels for different purposes and individual species in a water body varies, pH values between 6.50 and 8.50 generally indicates good water quality (Tchobanoglous *et al*., 2003; Chapman, 1996)

Arceivala (1981) reported that the die-off rate of the micro-organisms was accelerated when pH of the pond water was greater than 9.3. Hodgson & Larmie (1998) showed that there were no coliforms present in final effluent from maturation pond with pH above 10.7. This indicates that with a pH below this value, micro-organisms are able to strive well in the WSP effluent.

2.8.3 Electrical Conductivity

Conductivity is the mobility of ions to conduct electrical current. This depends on the ionic strength of the water sample. The measurement of the electrical conductivity offers a speedy and appropriate way of assessing the concentration of the electrolytes in solution (Chapman, 1996). Conductivity is also a good measure of salinity in water. The measurement detects chloride ions from the salt. Salinity affects the potential dissolved oxygen levels in water. The greater the salinity level, the lower the saturation point (Okoh, 2010).

2.8.4 Total Suspended Solids

Total Suspended Solids (TSS) is a determination of the amount of all suspended particles in water. Total suspended solids in water are usually as a result of sediment carried by the water. High Total Suspended Solids in water is an indication of poor water quality (Tchobanoglous *et al*., 2003; Chapman, 1996).

2.8.5 Nitrate-Nitrogen

Nitrate-Nitrogen (NO_3-N) is a measure which indicates pollution by human or animal waste or fertilizer run-off. Nitrate-Nitrogen tends to stimulate algal growth and indicate possible eutrophication condition. It is also considered as a primary driver of eutrophication of aquatic ecosystems; increased concentration of this nutrients leads to increased primary productivity in a water body (Chapman, 1996).

2.8.6 Ammonia-Nitrogen

Ammonia-Nitrogen (NH_3-N) is a measure which indicates organic pollution by municipal or community waste. Organic nitrogenous matter is destroyed by microbiological activity with the production of ammonia. In anaerobic conditions, ammonia can result from natural reduction processes. Ammonia at high levels are toxic to aquatic life and therefore, unfavorable to the ecological balance of water bodies at certain pH levels (Chapman, 1996).

2.8.7 Phosphorus

Phosphorus (P) is the measure of the total phosphorus, total dissolved phosphorus and dissolved reactive or orthophosphorus in a water body. Phosphorus is known to be the main driver of eutrophication of aquatic ecosystems; increased concentration of phosphorus leads to increased primary productivity in a water body (Tchobanoglous *et al*., 2003; (Chapman, 1996).

2.8.8 Sodium absorption ratio (SAR)

Measure of ‘sodium hazard’ of irrigation water.

$$\mathrm{SAR} = \frac{[\mathrm{Na}+]}{[0.5([\mathrm{Ca}^{2}+] + [\mathrm{Mg}^{2}+])]\ 0.5}$$

For safe irrigation, the SAR should be less than 18. High values of sodium absorption ratio SAR indicate that sodium in the irrigation water may replace the calcium and the magnesium ions in the soil, possibly causing damage to the soil structure. (Tchobanoglous *et al.*, 2003; Chapman, 1996).

2.8.9 Dissolved Oxygen

Dissolved Oxygen (DO) is a measure of the oxygen concentration in a water body. It is an important component of aquatic systems and its measurements offers a good signal of water quality. It is usually used as a measure of water quality such that, high values of DO levels indicate good water quality. Variations in DO concentration can be an immediate signal of varying conditions in the water body (Tchobanoglous *et al*., 2003; Chapman, 1996).

2.8.9.1 Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) is a measure of the amount of oxygen consumed from aquatic environments by aerobic micro-organisms for their metabolic activities. A water body with a high BOD tends to have low Dissolved Oxygen (DO) concentration (Tchobanoglous *et al*., 2003; Chapman, 1996).

2.9 Biological Characteristics

The biological components of a water body are of different species, ranging from single-celled microbes to multi-cellular organisms. Both bacteria and fungi play a role in the chemical breakdown of contaminants in a water body (Chapman, 1996).

2.9.1 Chlorophyll- a

Chlorophyll-a (Chl-a) is the degree of the photosynthetic pigment present in aquatic algae. It is a significant biological measurement generally used to measure the total biomass of algae present in a water body (Chapman, 1996).

2.9.2 Microbiological Indicators

The most common risk to human health associated with water stems from the presence of disease-causing micro-organisms. Many of these micro-organisms originate from water polluted with human excrement. Human faeces can contain a variety of intestinal pathogens which cause diseases ranging from mild gastro-enteritis to the serious, and possibly fatal dysentery, cholera and typhoid. Total Coliform, Faecal Coliform and Escherichia Coli (*E. coli*) measurements are used to determine the presence of pathogenic organisms in a water body in order to prevent diseases. They indicate the presence of faecal contamination from either animal or human wastes (Chapman, 1996).

2.9.3 Sludge Quality

2.9.4 Organic Matter

Organic matter represents the fraction of the soil that is composed of both living organisms and once-living residues in several stages of decay. Several factors affect the level of organic matter that can be maintained in a soil. Among these are organic matter additions, moisture, temperature, tillage, nitrogen levels, cropping, and fertilization. Soil organic matter content is also useful in developing management plans for land application of municipal sewage sludges and other wastes. Excessive nitrogen applications stimulate increased microbial activity, which in turn speeds organic matter decomposition. The extra nitrogen narrows the ratio of carbon to nitrogen in the soil. Native or uncultivated soils have approximately 12 parts of carbon to each part of nitrogen, or a C: N ratio of 12:1.

2.9.5 Total Nitrogen

Total Nitrogen measures the total amount of N present in the soil, much of which is held in organic matter and not directly available to plants. Nitrogen has to be in a mineralised form (Nitrate or Ammonia) to be freely available to plants. The nitrogen in these organic matter pools is mineralised to form Nitrate and Ammonia during the season, becoming plant available for crop growth.

2.9.6 Total Phosphorus

Total Phosphorus determines the total amount of phosphorus in the soil, both available and unavailable. This can be a useful tool in assessment of the soil’s phosphorus storage capacity and overall decline or mining of soil phosphorus. (Moody, (2007)

2.9.7 Potassium (K)

The total K in soil will be dependent on soil parent material, the extent of weathering and leaching of soil minerals, the type of clay minerals, soil texture, organic matter content and K fertilizer history. Much of the potassium occurring in soils is not available to plants and crops. Therefore, soils containing high levels of K can still be responsive to K fertilizers. Brennan and Bell (2013)

2.9.8 Heavy Metals

2.9.8.1 Lead

Lead is a highly poisonous metal (regardless if inhaled or swallowed), affecting almost every organ and system in the body (Jagadish, 2010). Whenever lead finds its way into the human body, it can cause severe brain damage and malfunctioning of bone marrow which leads to deficiency in the production of blood cells which may cause leukemia (Counter et al., 1998). Lead reduces sperm count in males and it can also create a damaging effect on the liver, kidney, nervous system, blood vessels and other tissues (WHO, 2004).

2.9.8.2 Copper

Copper is a component of most vital enzymes; including tyrosinase, cytochrome oxidase, and amine oxidase. The metabolism of copper involves a turnover of the copper-containing enzymes. At high concentrations of Cu, it can become highly toxic causing symptoms such as chlorosis and necrosis, stunting, leaf discoloration and inhibition of root growth (Kari et al., 2008). Copper in the blood exist in two forms: bound to ceruloplasmin (85–95%) and the rest is loosely bound to albumin and small molecules (Faller, 2009). Copper has a tendency to accumulate in the blood and deplete the brain zinc supplies. Excess copper intake causes stomach upset, nausea, and diarrhoea and can lead to tissue injury and disease.

Acute symptoms of copper poisoning by ingestion include vomiting, hematemesis, hypotension, melena, coma, jaundice and gastrointestinal distress (Brewer, 2007). Other conditions linked to copper deficiency include osteoporosis, osteoarthritis, rheumatoid arthritis, cardiovascular disease, colon cancer, and chronic conditions involving bone, connective tissue, heart and blood vessels. Excess copper intake causes stomach upset, nausea, and diarrhoea and can lead to tissue injury and disease.

2.9.8.3 Chromium

Chromium causes respiratory problems, a lower ability to fight diseases, birth defects, infertility and tumor formation. Chromium (III) is an essential nutrient for humans and shortages may cause heart conditions, disruptions of metabolisms and diabetes. Excess chromium (III) causes negative health effects for instance skin rashes and cause cancer (Cheryl and Susan, 2000).

2.9.8.4 Zinc

Zinc (Zn) is an essential trace element. It plays roles in all replications and acts as a cofactor in enzymes. High concentrations of Zn can cause damages to human body (disturbances in energy metabolism or increase in oxidative stress) (Samadi-Maybodi and Rezaei, 2014).

Excess Zn may cause oxidative stress and negatively affect photosynthetic efficiency. The above-mentioned problems, make it relevance to monitored Zn in the sewage sludge which could be used in soil.

2.9.8.5 Cadmium

The WHO recommended level of Cd in drinking water is 0.005 mg/l, above which it affects people (WHO, 2011). The accumulation of Cadmium in food crops at sub-phytotoxic levels has a significant effect on the consumers in the short- and long-term periods, although its toxic effect is determined more by its form and not its concentration (Oliver, 2011 Alloway 1995). Long-term exposure can cause damages to the kidney, liver, circulatory and nerve tissues (WHO, 2000). Acute Cd toxicity has been reported at 75mg/kg. According to Tandon (1994), excessive intake of Cd through rice eating resulted in severely painful and crippling conditions (Itai-Itai) in Japanese women. Concentrations of 2.50 mg/kg from industrial emissions in Luvkgestal in Netherlands were found to cause increased body burden and altered kidney functions Alloway, (1995)

CHAPTER THREE

METHODOLOGY

3.0 Introduction

3.1 Description of Study Area

This research study was conducted on the sewage treatment plant at University of Ghana, Legon campus, which was constructed close to the Onyease stream, which flows through the Legon botanical garden. Wastewater converges from the University of Ghana, Presbyterian Boys Senior High School, University of Professional Studies, Achimota Senior High School and currently the Achimota Hospital into the ponds for treatment. The effluent is discharged into the Onyease stream. The Legon wastewater treatment plant is the oxidation pond system. The system comprises three treatment streams. The wastewater from the various institutions converges to the various pumping station, where the wastewater is either pumped or moved by gravity to the treatment site. The wastewater from the pumping stations is channelled into a rectangular inlet structure at the site. This structure has a wide screen and here all non-biodegradable materials are removed (Primary treatment). The liquid waste then flows into a distribution chamber and from there it flows into three grits channels with each connecting to each treatment stream. Each stream consists of an anaerobic pond, facultative pond, maturation pond 1 and maturation pond 2 with an outlet. For the purposes of this study the sampling sites will be identified as Anaerobic stream-1(AS-1) Anaerobic stream-2 (AS-2) Facultative stream-1(FS-1) Facultative stream-2(FS-2)Maturation stream-1(MS-1) Maturation stream-1-2(MS-1-2) Maturation stream-2-1(MS-2-1) Maturation stream-2-2(MS-2-2)as indicated in Figure 5 showing the sampling sites. There is a laboratory at the site, where a laboratory technician is employed and monitors the daily performance of the treatment system.

University of Ghana is located in the Greater Accra Region of Ghana. The population of University of Ghana is about 50,000. (University of Ghana 2019)

The University of Ghana the premier university and largest University in Ghana was established as the University College of Gold Coast by ordinance on August 11th 1948 for the purpose of providing university education, learning and research.

The Legon sewage treatment plant (WSP) was constructed to help in the disposal, storage and treatment of liquid waste generated in the university community and to ensure good environmental health. The ponds at Legon campus were constructed and commissioned in 2012.

3.2 Climate and Vegetation

The mean ambient temperature, rainfall and humidity for Accra are 32.0 ^{o}C, 300 mm annum and 57.7 percent, respectively.

The development of vegetation is closely related to climatic factors, soil types and of course, man who over the years has greatly modified the original vegetation by his economic activities. The Accra Plains form part of the coastal scrub and grassland, which receives the least amount of precipitation in Ghana (Benneh & Dickson, 1980). The Plains supports a vegetation of short grassland with small clumps of bush and a few isolated trees (e.g. Baobab and neem trees). Patches and clumps of forest trees, bamboos and palm occur occasionally in stream valleys at the foot of the Akwapim-Togo ranges e.g. Near Teiman, Ashongman, Dodowa and Ayikuma. Also scattered or at intervals along the main stream valleys on the plains are thick mangrove trees and scrubs. In the northern part of the plains between Doryum, Agomeda, Somanya and Akuse, where rainfall is appreciably higher and much better distributed and more uniform, there is a gradual change to the typical savannah type of vegetation in which there are more trees.

3.2.1 Geology and Minerals

The Dahomeyan structure arises basically as alternating belts of acid and basic gneisses.

The acid Dahomeyan cluster comprises of two alternating belts. The first belt lies to the immediate east of Togo-Akwapim ranges encompassing from the coastal plains of Accra to Kpong in the north-east direction. It encloses a series of disconnected linear Togo quartzite outliers.

The basic Dahomeyan rocks could also be subdivided into two groups – the metabasics and the basic intrusive. (Kesse. (1985). Figure one and two shows the location of the sampling site and aerial view of the treatment plant.

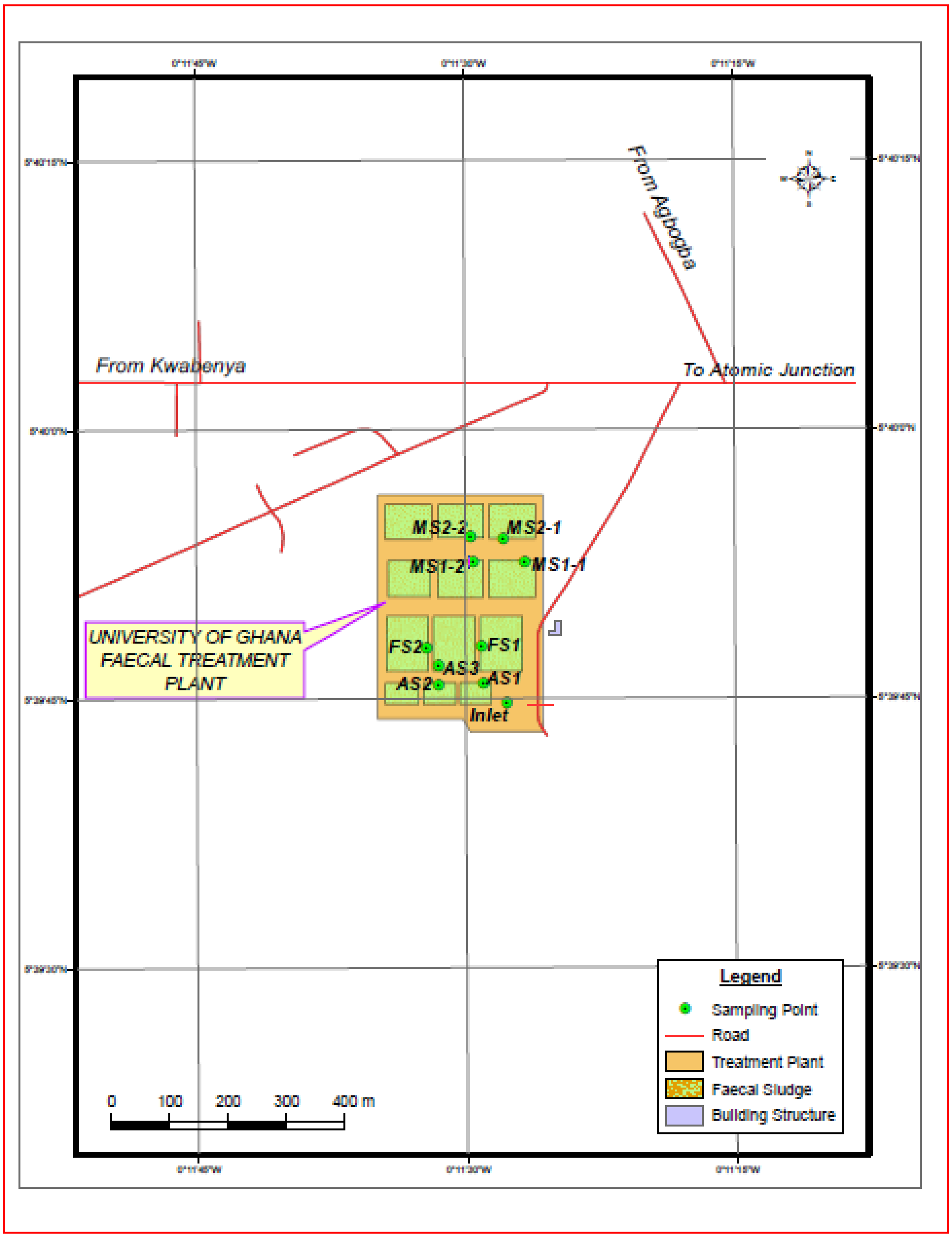

Figure 1: Sampling site Location.

Source: Water Research Institute (Cartographic Department)

Figure 2: AERIAL VIEW OF THE SAMPLING SITE

3.3 Sampling

In all a total of thirty-six (36) wastewater samples were taken for analysis. Samples were transported to the CSIR-Water Research Institute laboratory immediately for analysis. The samples were taken from the sedimentation tank and the maturation two (2) ponds at Legon (WSP). Samples were taken for a period of six (6) consecutive months between the months of October 2017 and March 2018.

Whiles a total of forty-eight (48) sludge samples were collected from the two streams WSP (i.e.) Anaerobic stream-1 Anaerobic stream- 2 Facultative stream and-1and 2 ponds and Maturation stream 1and 2 ponds. The table below explains how samples were collected.

Table 2: Research Design for sampling

Influent from sedimentation tank (an hourly sampling was done for three hours each month October 2017-March 2018)	3x6=18
Effluent from maturation 2 pond (an hourly sampling was done for three hours)	3x6=18
Total number of influent and effluent samples	**36**
Sludge samples	
Anaerobic stream (AS-) 1&2 (sludge was scooped from the four corners and the middle of the pond and treated as composite sample.	2x6=12
Facultative stream (FS) 1&2 (sludge was scooped from the four corners and the middle of the pond and treated as composite sample.	2x6=12
Maturation stream-1(MS) 1&2 (sludge was scooped from the four corners and the middle of the pond and treated as composite sample.	2x6=12
Maturation stream-2(MS) 1&2 (sludge was scooped from the four corners and the	2x6x12

middle of the pond and treated as composite sample.	
Total number of sludges	**48**

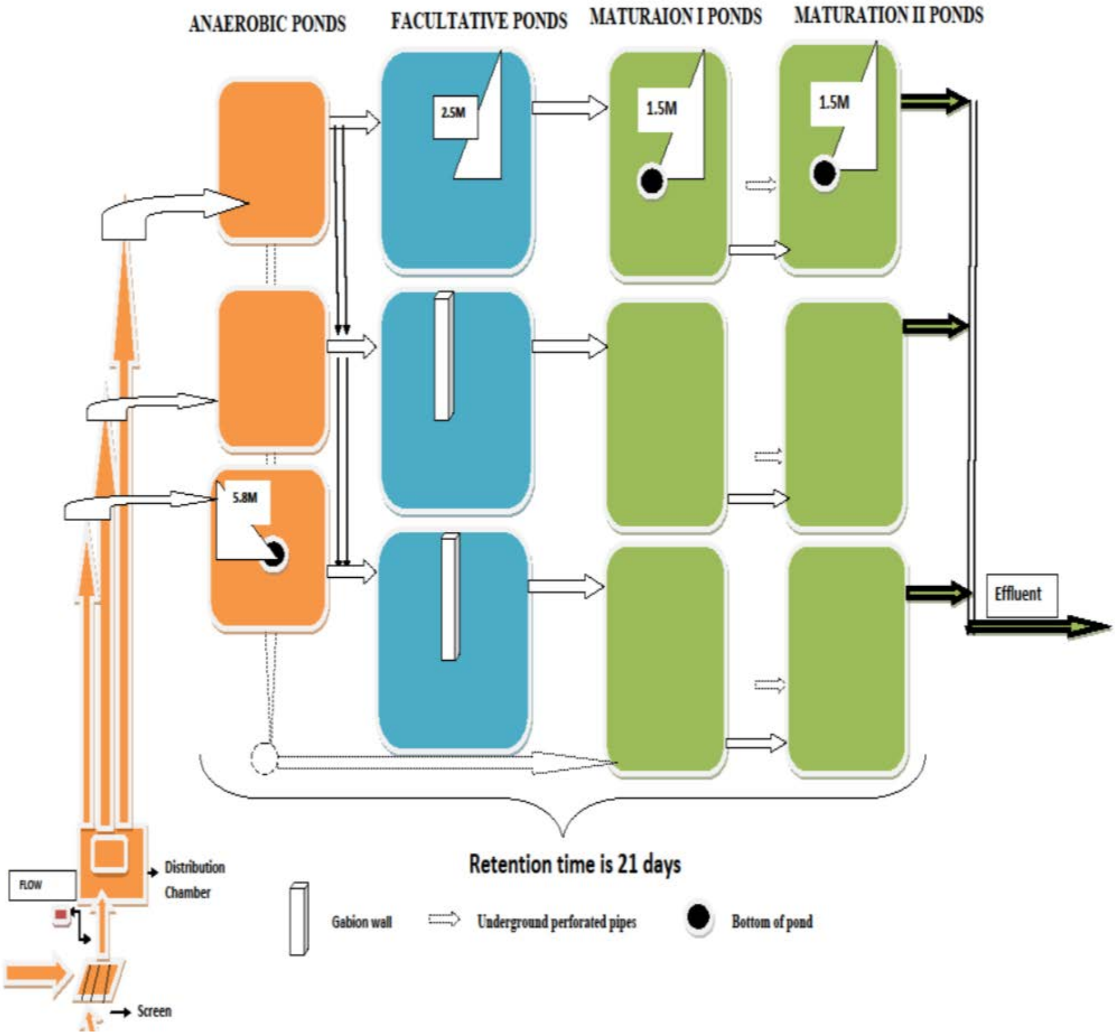

Figure 3: Schematic diagram of the Accra Sewage Treatment Plant

Temperature, pH and conductivity were taken in situ using muilt-parameter analyser. Samples for Dissolved Oxygen (DO) were collected in airtight glass bottle. Sampling was carefully done to avoid dissolving atmospheric oxygen. Dissolved Oxygen was fixed in the field using Winkler 1 and 2 solutions, (manganous sulphate monohydrate $MnSO_{4}.H_{2}0$) and (alkali-iodide-azide solution) respectively. Fixed samples were transported to the laboratory under dark conditions. Samples for BOD were collected as was done for DO but without fixing oxygen. Samples were stored in an ice chest at temperature of about 4^{o}C and transported to the CSIR-Water Research Institute laboratory. Samples for nutrients and other chemical parameters were collected using clean plastic bottles of one litre volume.

Samplings for bacteriological parameters were collected using a pre-sterilized bottle of 300ml volume. Bacteriological samples were stored with ice packs in an ice chest. All samples were conveyed to the laboratory for analysis. Figures: 7 and 8 shows how samples were collected from the anaerobic digestion thank and the facultative pond.

Figure 4: Sampling from anaerobic digestion tank

Figure 5: Sampling from the facultative pond

3.4 Parameter of environmental concern Analyzed on waste water

3.4 Physico-Chemical parameters

Physico-Chemical parameters analysed includes: Total Suspended Solids (TSS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonium-Nitrogen, Nitrate-Nitrogen, Phosphate, pH, Conductivity, Total Dissolved Solids (TDS), Lead, Copper, Zinc, Nickel, Cadmium and Chromium. Bacteriological parameters analysed were: Coliform bacteria, *E. coli.*

3.4.1 Determination of Conductivity Using Laboratory Bench Conductivity Meter

The conductivity cell and the beaker or vessel into which a portion of the sample is to be examined was thoroughly rinsed. The beaker was completely filled with sample. The cell was inserted into the sample holding container. When the sample and cell reach the same temperature, the indicated value was read off (conductivity) on the meter. Results are expressed as µS/cm or mS/cm (APHA, 2012) 22nd edition.

3.4.2 Total Dissolved Solids (TDS) Determination Using Gravimetric Method

Water sample was well mixed by shaking it several times and 100ml volume was poured onto a glass-fibre filter using a measuring cylinder and vacuum was applied. The filtrate collected was transferred into a weighed evaporating dish and evaporated to dryness on a steam bath. The evaporated sample was dried for at least 1hour in an oven at 180±2°C. It was then cooled in a desiccator to attain room temperature and weighed. The TDS of the sample was determined based on the calculation/equation indicated below

Calculations/equation

TDS (mg/l) = (A-B) × (1000)/volume of sample (ml)

Where

A = dried residue weight + dish (mg)

B = weight of dish (mg) (APHA, 2012).

3.4.3 Total Suspended Solids (TSS) Determination Using Gravimetric Method

A filtering apparatus and a glass-fibre filter were set up for the filtration. The filter was soaked with distilled water to seat it. Water sample was well mixed by shaking it several times to obtain a homogenous particle size and (100ml) volume was poured onto a glass-fibre filter using a measuring cylinder and vacuum was applied. The filter was carefully removed from filtration apparatus and transferred onto a weighing dish. It was dried for at least 1hour between 103 to 105°C in an oven and then cooled in a desiccator to a room temperature and weighed. The total suspended solids (TSS) was then calculated as;

Calculations

TSS (mg/l) = (A-B) × (1000)/volume of sample (ml)

Where

A = weight of dish and filter + dried residue (mg)

B = weight of dish and filter (mg) (APHA, 2012).

3.4.4 Determination of Dissolved Oxygen (DO) Using Winkler Method

Procedure

To a fixed DO water sample, 2ml conc. sulphuric acid was added. The bottle was corked and mixed by inverting several times until dissolution was complete. The dissolved sample was titrated with 0.025M sodium thiosulphate ($Na_2S_2O_3$) solution to a pale straw colour. Few drops of starch solution were added and titration continued till the fading of the blue colour. Dissolve Oxygen concentrations were calculated and results expressed as mg DO/L to two decimal places using the calculation: The dissolve oxygen concentrations (DO) was then calculated as;

mg DO/L = A×M×8000 ml sample

Where:

A = ml titrant

M = Molarity of $Na_2S_2O_3$

8000 = milliequivalent weight of oxygen x1000 ml/l

3.4.5 Biochemical Oxygen Demand (BOD) Determination Using Dilution Method (Winkler Azide Modification)

Procedure

Wastewater samples collected were diluted with oxygenated distilled water and incubated at 20^0C for 5 days. Dissolved oxygen (DO) concentration was measured before and after incubation. The BOD was calculated from the difference between the initial and final dissolved oxygen.

Day one dissolved oxygen sample was fixed with 2ml $MnSO_4$ followed by 2ml Alkali-Iodide-Azide solution in BOD bottle. The fixed sample was shaken thoroughly by inverting several times. Precipitate was allowed to settle. After precipitate had settled, 2ml conc. sulphuric acid (H_2SO_4) was added. The bottle was corked again and inverted several times to dissolve the precipitate which gives an intense yellow colour. 100ml of solution was titrated with sodium thiosulphate ($Na_2S_2O_3$) to a pale-yellow colour. One ml of starch was added as an indicator with colour changing from pale yellow to blue. The titration was continued till the fading of the blue colour. The biochemical Oxygen demand concentrations was then calculated as;

Calculation

$BOD_{5,}$ (mg/l) = (D1-D2)/P

Where

D1 = Dissolved oxygen (DO) of sample immediately after preparation, mg/l

D2 = Dissolved oxygen (DO) of sample after 5-day incubation at 20^0C, mg/l

P = Decimal volumetric fraction of sample used (APHA, 2012).

3.4.6 Determination of Chemical Oxygen Demand (COD) Using Closed Tube Reflux Method

Procedure

Sample and distilled water serving as blank was placed in digestion culture tubes and solution added. Sulphuric acid with silver sulphate reagent was carefully run down inside of vessel to form an acid layer under the sample-digestion solution layer. Tubes were tightly capped and swirled several times to mix completely. Tubes were placed in block digester preheated to 150 ± 1^0C, and refluxed for 2hrs behind a protective shield. They were cooled to room temperature in a culture tube rack. The digested sample was transferred into a conical flask followed by 1 to 2 drops Ferroin indicator. Stirring was done rapidly while titrating with standard 0.1M FAS. The end point of a sharp colour change from blue green to reddish brown was noted. The chemical Oxygen demand concentrations was then calculated as;

Calculation

COD as mgO_2/L = (A-B) × M × 8000/ml sample

Where

A = ml Ferrous Ammonium Sulphate used for blank

B = ml Ferrous Ammonium Sulphate FAS used for sample

M = molarity of Ferrous Ammonium Sulphate

8000 = milli equivalent weight of oxygen × 1000ml/L (APHA, 2012).

3.4.7 Determination of Ammonium-Nitrogen Using Direct Nesslerization Method

Procedure

One to five (1-5ml) wastewater sample was pipetted and dilute in a 50ml volumetric flask with ammonia free distilled water. The diluted sample was poured into a conical flask and two drops of Rochelle salt solution was added to the diluted sample. It was mixed well and 2ml of Nessler’s reagent added. The blank was prepared (50ml of ammonia-free water plus 5 drops

Rochelle salt and 2ml Nessler's reagent). Samples were allowed to stand for 10 minutes to go through reaction for colour development and their absorbance determined using the UV/VIS spectrophotometer at a wavelength of 410nm using a 1cm light path cuvette. The spectrophotometer was zeroed with the blank solution.

3.4.8 Determination of Nitrate-Nitrogen Using the Hydrazine Reduction Method

Procedure

Ten (10ml) of the sample or an aliquot was transferred into a test tube. Gently 1.0ml of 0.3M NaOH was added and mixed thoroughly. Gently 1.0ml of reducing mixture was added and mixed thoroughly. It was heated at 60 ^{0}C for 10 minutes in a water bath. It was cooled to room temperature and 1.0ml of colour developing reagent added. It was inverted to mix and the absorbance was read at the wavelength 520nm.

3.4.9 Determination of Phosphate Using the Stannous Chloride Method

Procedure

To a clear 100ml sample, 4ml of molybdate reagent 1 which contains 25g $(NH_4)_6MO_7O_{24}.4H_2O$ in 175ml distilled water, 280ml concentrated H_2SO_4 and 400ml distilled water was added to the sample. Ten (10) drops of stannous chloride reagent was added with thorough mixing. After 10 minutes, but before 12 minutes, absorbance was measured at wavelength of 690nm on the spectrophotometer. The spectrophotometer was zeroed with a blank solution (this solution was prepared in the same way as samples except that instead of 100ml sample, 100ml distilled water was used).

3.5 Biological Analysis

Total Coliform and *E. coli* analysis were conducted based on Standard Methods for the

3.5.1 Determination of Coliform Bacteria and *E.Coli* Using the Membrane Filtration Technique

Procedure

Wastewater samples were serially diluted to make microbial load countable. The suitable dilutions were filtered through a membrane filter with the aid of sterilised forceps; the filters were transferred onto Petri dishes of HiCrome^{TM} Coliform Agar. The Petri dishes were incubated at 37± 0.5^{0}C for 24hrs.

3.5.2 Expression of Results

Typical Coliform colonies appeared pinkish to red in colour while that of *E. coli* appeared bluish to violet. Each of the colonies was counted and multiplied by the dilution factor. Results were expressed as colony forming units per 100ml of sample analysed (i.e. c.f.u/100ml).

3.6 Parameters of interest Analyzed on Sludge

pH, Conductivity, Organic matter, Organic carbon, Total Nitrogen, Total Phosphorus, Available Phosphorus, Potassium, Lead, Copper, Zinc, Nickel, Cadmium and Chromium.

3.6.1 pH

Procedure

Fifty grams of fine sludge was weighed into a 100 ml polythene wide-mouth type bottle. A volume of 125ml of water solution was added and the bottle capped. It was shaking with a shaker for two hours. After the shaking, it was allowed to settle. The clear part of the mixing sample was measured. Before the measurement the sample was gentle agitated by hand. A pH probe was immersed into the cleared part of the solution. pH value was read when the reading was stabilized (accuracy 0.1 unit)

3.6.1.2 Determination of Conductivity Using Laboratory Bench Conductivity Meter

Fifty grams of fine sludge was weighed into a 100 ml polythene wide-mouth type bottle. A volume of 125ml of water solution was added and the bottle capped. It was shaking with a shaker for two hours. After the shaking, it was allowed to settle. The clear part of the mixing sample was measured. Before the measurement the sample was gentle agitated by hand. The conductivity probe was inserted into the bottle containing the sample. When the upper part of suspension (water) and cell probe was stabilized the indicated value was read (conductivity) on the meter (accuracy 0.1 unit) Expressions of results are expressed µS/cm or mS/cm (APHA, 2012) 22nd edition.

3.6.2 Total Nitrogen: Persulphate digestion method

Procedure

Five grams sludge was ground and passed through a 0.5 mm sieve. One-gram fine sludge was weighed (accuracy 0.001 g) into a digestion tube which contains prepared digestion mixture. Two blanks and a reference sample were added to each batch of sample. It was then heated for 30 minutes at temperature of (105°C).

It was then allowed to cooled to room temperature and measured with the UV/VIS 6000 spectrophotometer at a wavelength of 356nm.The total nitrogen concentration was express as;

Calculation

$$\%\mathrm{N} = \frac{\mathrm{a-b}}{\mathrm{s}} \times \mathrm{M} \times 1.4 \times \mathrm{mcf}$$

Where

a = Concentration of sample

b = Concentration of blank

s = air-dry sample weight in gram

1.4 = $1.4 \times 10^{-3} \times 100\%$ (14 = atomic weight of nitrogen)

mcf = moisture correction factor

3.6.3 Total Phosphorus: PhosVer 3 acid persulphate digestion method

Procedure

Similar procedure of the total nitrogen is applied in this protocol. Five grams sludge was ground and passed it through a 0.5 mm sieve. One-gram fine sludge was weighed (accuracy 0.001 g) into a digestion tube containing prepared PhosVer 3 acid persulphate digestion mixture. Two blanks and a reference sample were added to each batch of sample. It is then heated for 30 minutes at temperature (105^{o}C). It was then allowed to cool to room temperature and measured with the UV/VIS 6000 spectrophotometer at a wavelength of 536nm

Calculation

$$\mathrm{P\ (mg/kg\ soil)} = (\mathrm{a}-\mathrm{b}) \times \frac{14}{1000} \times \frac{1000}{\mathrm{s}} \times \mathrm{mcf} = (\mathrm{a}-\mathrm{b}) \times \frac{14}{\mathrm{s}} \times \mathrm{mcf}$$

Where

a = mg/1 P in sample extract

b = ditto in blank

s = sample weight in gram

mcf = moisture correction factor

Conversion factor: $P_2O_5 = 2.31 \times P$

3.6.4 Soil Organic Matter and Carbon Tests (Walkley and Black, 1934)

Procedure:

An amount of 0.1-gram dried weighed sludge passed through <60 mesh was weighed and transferred to a 500-ml Erlenmeyer flask. Ten (10ml) ml of 0.167 M $K_2Cr_2O_7$ was added by means of pipette dispenser. It was followed by adding gently 20 ml of strong H_2SO_4 by means of dispensing and swirled gently to mix. It was allowed it to stand for 30 minutes reaction time. A volume 200ml of distilled water was added to it to give a clearer suspension for observing the endpoint.10 ml of 85% H_3PO_4, was added using a suitable dispenser.

Ten (10) drops of Ferroin indicator was added for observing the endpoint. It was titrated with 0.5 M Fe^{2+} solution to endpoint wine red. A reagent blank was prepared using the above procedure without sludge and then titrated.

To calculate Carbon and Organic matter

(a) %Carbon

$$\%C = \frac{(B-S) \times M \text{ of } Fe2+ \times 12 \times 100}{\text{g of soil} \times 4000}$$

Where:

B = mL of Fe2+ solution used to titrate blank

S = mL of Fe2+ solution used to titrate sample

12/4000 = milliequivalent weight of C in g.

(b) % *Organic Matter*

$$\% OM = \% \text{ total C} \times 1.72$$

3.7 Trace metals in sludge

For the solubilisation of samples, the sludge sample was air dried, ground and passed through a sieve with a mesh size of 315µm. A portion of the sample about 0.2 g of dry weight (DW) was weighed into a Teflon digestion crucible and digested under pressure with concentrated 2.5 ml Nitric acid HNO_3 (Analar Grade) by slow heating to 80 °C followed by rapid heating to 160 °C (Stoeppler and Backhaus, 1978). The temperature was maintained at 160 °C for 7 to 8 hours. Digested samples were normally devoid of solids and colourless or slightly yellow. These were made up to 50 ml with deionised water and analysed for trace metals using a Agilent Technologies 200 Series AA Atomic Absorption Spectrophotometer Cadmium (Cd), Chromium (Cr) Copper (Cu), Zinc (Zn), Iron (Fe), and Nickel (Ni), were determined by flame atomization (UNEP *et al.*, 1984a) and Arsenic (As) was determined by hydride generation atomic absorption spectrometry. (UNEP *et al.*, 1984b).

3.8 Analytical Procedures

The extract for each sludge sample was analyzed for Pb, Cu, Cr, Zn, Ni, Cd and As using Agilent Technologies 200 Series AA Atomic Absorption Spectrophotometer with their respective Agilent hollow cathode lamps. Wavelengths of 217.0 nm, 324.8 nm, 357.9 nm, 213.9 nm, 232.0 nm,228.8nm and 193.7nm were used to measure absorbance’s of Pb, Cu, Cr, Zn, Ni, Cd and As, respectively. Before analysis was done, the AAS machine was calibrated. Salts of potassium dichromate, lead nitrate, copper sulphate, zinc nitrate and iron nitrate were used to prepare known concentrations of 0.200 mg/l, 0.400 mg/l, 0.600 mg/l, 0.800 mg/l, 1.00 mg/l, per salt in 100 ml flasks after additions of 1.5 mg/ml of strontium chloride (APHA, 2012). These salts were used as standards and a calibration curve was drawn from them in the instrument before unknown samples were read. This was done for every water and sludge sample. The addition of strontium chloride to the preparation of the calibration standards was to take care of interference in absorption of the specific metal by other metals at the same wavelength and therefore acting as a buffer and to minimize ionization of the metal atoms (APHA, 2012).

Figure 6, 7, 8 and 9 shows the preparatory process of sample for analysis.

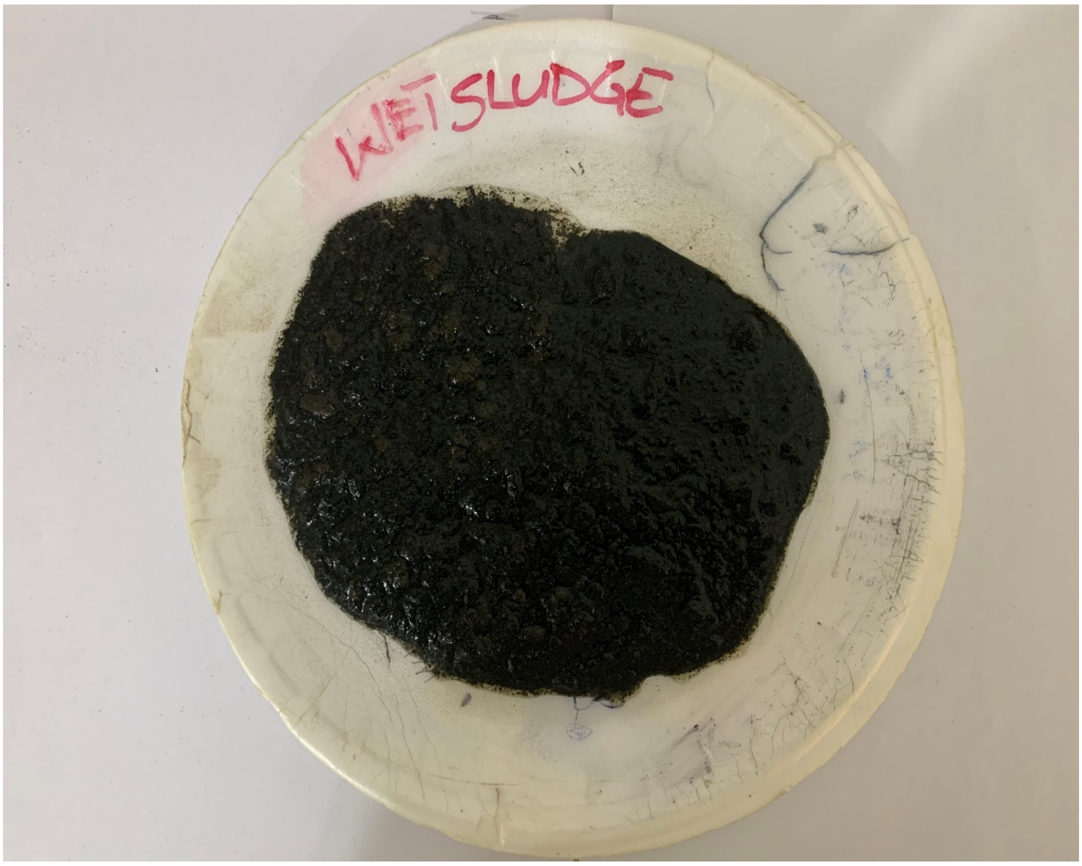

Figure 6 : Air drying of wet sludge sample

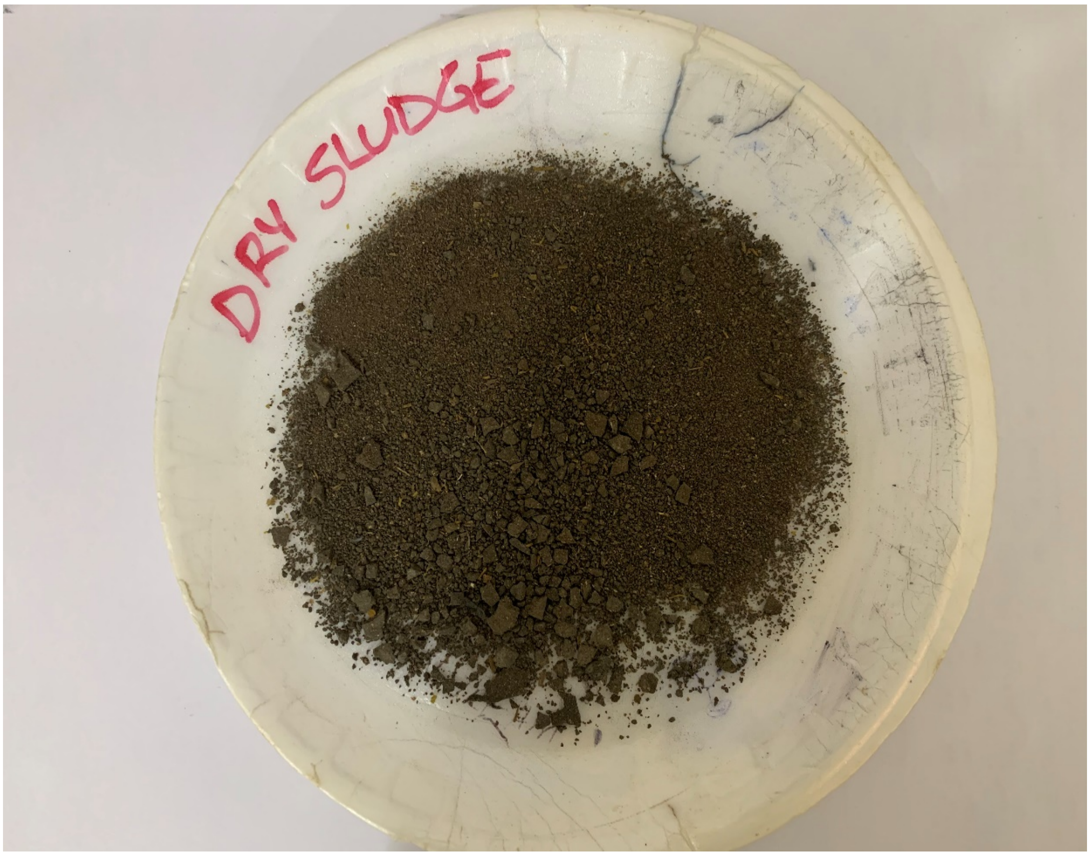

Figure 7: Dried grind and sieved sludge sample

Figure 8: Diluting digested sample for heavy metal analysis

Figure 9: Using Atomic Absorption Spectrophotometry for heavy metal measurement

3.9 Data analysis and presentation

The data obtained from the field was analysed using ANOVA, t-test at 0.05 level of significance ($p \leq 0.05$) and Microsoft excel program 2017 was used for analysis of statistical values; average and their standard deviations. The data was presented in the form of tables, line graphs (trend analysis) and error bar charts. Removal efficiency calculations: The concentration-based efficiency (E) was computed according to Equation

$$E_T (\%) = \frac{Ci-Ce}{Ci} \times 100$$

Where:

ET is Total efficiency of the ponds

Ci is influent concentration to the ponds

Ce is effluent concentration from the pond

Heavy metals in sludge data was compared with the Limits for metals brought to agriculture land by sewage sludge in South Africa (SFS, 1998:944; Water Research Commission, 1997. The results were expressed as mg per kg sludge and mg/l for the effluent.

CHAPTER 4

ANALYSIS OF RESULTS AND DISCUSSION

4.0 Introduction

Results obtained from the treatment process monitoring and performance evaluation analysis of the WSP at Legon are presented and discussed in this chapter in two parts. The first part consist of the performance evaluation analysis study which used the data obtained from the monitoring of the WSP at two different locations at Legon, namely, inlet(sedimentation tank) of the WSP, and maturation pond (final effluent) and the second refers to quality of the sludge in the eight different ponds namely Anaerobic pond 1&2, facultative Pond1&2, maturation(1)Pond 1&2,maturation(2) Pond1&2 of the WSP for six months period (October 2017 to March 2018). The data obtained from the monitoring is given in the Appendix-1 and Appendix-2 of this thesis. The treatment removal efficiency calculations and the trend analysis for the wastewater for the period are presented in a Table 3 and Figures 10, 11, 12 and 13. Figure 10 and 11 includes only BOD, COD, TSS, Ammonia, Nitrate-Nitrogen, Phosphate-Phosphorus and E. coli removal efficiencies while 12 and 13 includes only BOD, COD, TSS, Ammonia, Nitrate-Nitrogen and Phosphate-Phosphorus line graph trend analysis.

4.1 Evaluation of the treatment performance of the sewage ponds

The total suspended solids (TSS) concentration of the influent for WSP ranged from 194 to 595 mg/l with an average value of 408±34.5 mg/l as presented in (Table 3). The TSS of the treated effluent ranged from 60.0 to 86.5 mg/l with an average value of 70.3±2.8 mg/l. The mean overall TSS removal efficiency of the pond system was 82.8 per cent (Figure 10) which is very high. Hodgson, (2007) reported TSS removal of 83.5% in a similar study at Akosombo, Ghana. TSS removal of 46.0% was also observed in treatment ponds in Akuse (Hodgson, 2000). The presence of significant levels of total suspended solid in the treated effluent might have been due to the presence of algal cells or could be attributed to erosion of the soils nearby and debris washed into the ponds caused by rain water. It could also be due to high nutrients which leads to increased primary productivity. The average TSS concentration of the final effluent is unsatisfactory compared to the Ghana Environmental Protection Agency (EPA)-Ghana guideline value of 50 mg/l.

Tables 3 and 4: show removal efficiency calculations and Statistical significance differences of the (WSP). The concentration-based efficiency (E) was computed according to Equation

$$E_T (\%) = \frac{Ci-Ce}{Ci} \times 100$$

Where:

E_T is Total efficiency of the ponds

Ci is influent concentration to the ponds

Ce is effluent concentration from the pond

Table 3: Removal efficiency calculation (WSP)

PARAMETER	AVERAGE CONC. (mg/l) RAW Influent	AVERAGE CONC. (mg/l) FINAL Effluent	TREATMENT EFFICIENCY (%) Overall	EPA Guideline Values (mg/l)
Biochemical Oxygen Demand (BOD)	204±20.6	26.9±1.38	86.8	50.0
Chemical Oxygen Demand (COD)	820±70.87	135±2,23	82.8	250
Total Suspended Solid (TSS)	408±34.5	70.3±2.8	82.2	50.0
Ammonia-Nitrogen (NH_3-N)	13.4±0.36	1.98±0.18	85.2	1.00
Phosphate-Phosphorus (PO_4^{-3}-P)	4.09±0.21	1.69±0.10	58.7	2.00
Nitrate-Nitrogen (NO_3-N)	0.406±0.08	0.730±0.04	-	50.0
E. coli (cfu/100ml)	133,000,000	153,000	99.9	10

Table 4: Statistical significance of analysed results

Comparison of effluent and influent sewage qualities by student't-test

Parameters	Water types		t- statistics	p-value
	Treated	Untreated		
PH	8.6±0.14	7.3±0.03	9.15	< 0.0001
Cond	613±14.2	1084.6±65.6	-7.02	< 0.0001
TDS	362.94±7.98	642.3±40.5	-6.77	< 0.0001
TSS	70.3±2.8	407.8±34.5	-9.73	<0.0001
NH_3-N	1.97±0.18	13.41±0.36	-27.68	< 0.0001
NO_3-N	0.26±0.04	0.38±0.08	-1.12	0.24
PO4-P	1.69±0.10	4.09±0.21	-10.12	< 0.0001
COD	134.89±2.32	820.11±70.87	-9.66	< 0.0001
BOD	26.92±1.38	204±20.6	-8.57	< 0.0001

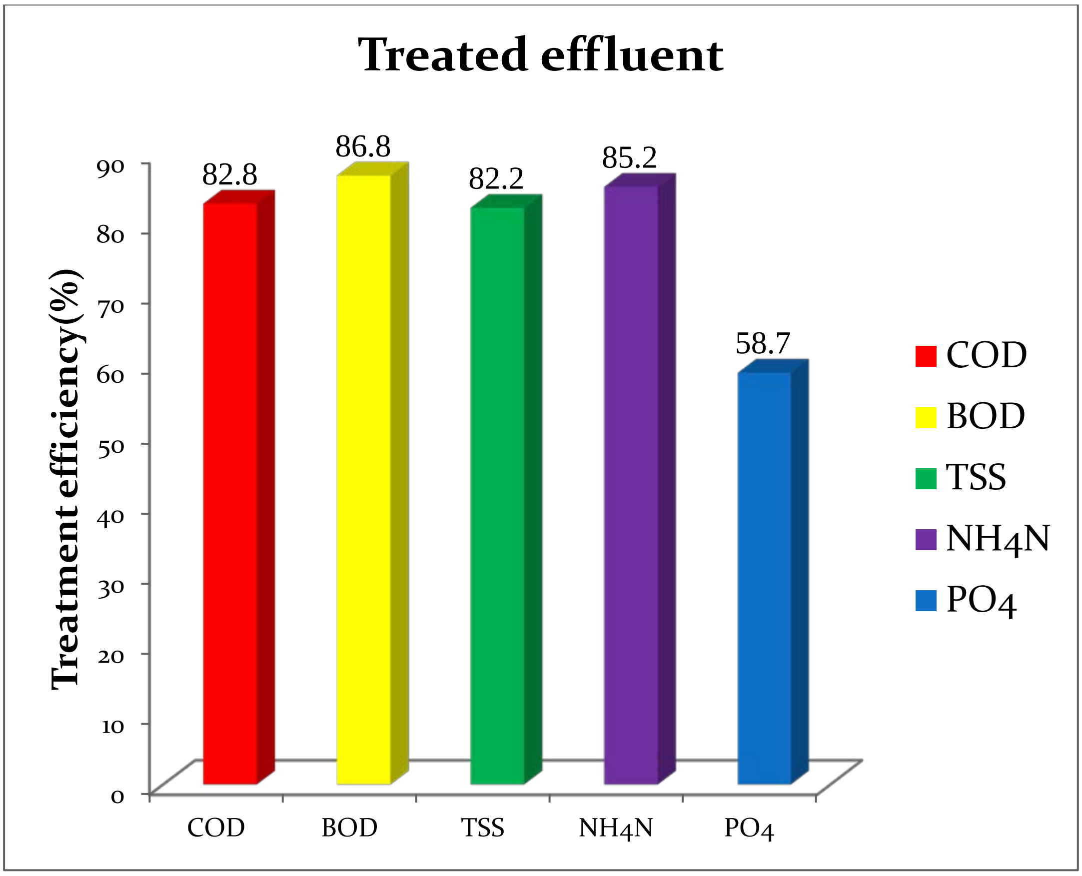

Figure 10: Treatment Efficiency of the treatment plant

4.2 Organic matter removal

4.2.1 BOD removal

The least BOD levels of the influent recorded was 106 and the highest was 352mg/l with an average value of 204±20.6 mg/l whilst that of the treated effluent ranged from 18.1 to 36.9 mg/l with an average value of 26.9±1.38 mg/l (Table 3). The strength of the influent could be considered as strong according to Mara, (1976). The mean overall BOD removal efficiency was 86.8 per cent (Figure 10) which is high and comparable to other waste stabilization ponds which gave BOD removal efficiencies greater than 70 per cent (Arceivala, 1981). About 64% of the BOD is removed in the primary facultative pond. The BOD/COD ratio has been proposed as indicator for biodegradation capacity (Metcalf and Eddy Inc., 1985). If BOD/COD ratio is more than 0.5 biodegradation will readily take place, if between 0.2 and 0.4 biodegradation will occur only in favourable thermal situation and if the ratio is below 0.2 biodegradation will not proceed (Contreras *et al*., 2003). It was found that domestic wastewater has typically a BOD/COD ratio between 0.4 and 0.8 (Metcalf and Eddy Inc., 1985) and as reference, a BOD/COD ratio of 0.4 is generally considered the cut-off point between biodegradable and not biodegradable waste (Uz *et al*., 2004). In this study, BOD/COD ratio in raw influent was around 0.25 which indicates that biodegradation will occur only in favourable thermal situation. The average measured BOD of the treated effluent level is low and acceptable compared to the EPA-Ghana guideline values of 50 mg/l.

4.2.2 COD removal

The COD levels of the influent were between 428 and 1283 mg/l with an average of 820±70.87 mg/L, whilst the final effluent COD level ranged from118 to 149 mg/l with an average of 135±2.23 mg/L (Table 3). The average total COD removal was 82.2 per cent (Figure 10) which is appreciable. The average measured COD level for the final effluent was satisfactory compared to the EPA-Ghana guideline value of 250 mg/l.

4.2.3 Nutrient removal

4.2.3.1 Ammonia Nitrogen removal

Ammonia concentration of the influent ranged from 11.3 to 15.5 mg/L with an average value of 13.4 mg/L. The ammonia nitrogen levels of the final effluent were between 1.23 and 2.55 mg/L with an average value of 1.98±0.18 mg/L (Table 3). The mean ammonium nitrogen removal efficiency was 85.2 per cent (Figure 10) which is appreciably high. The drop may indicate some rate of ammonium oxidation. According to Okoh (2010), the high influent values could be due to the anaerobic decomposition with the liberation of ammonia and the low final effluent values could be due to the volatilization of ammonia during the treatment processes.

The mean ammonia level of the final effluent was found to be unsatisfactory compared to the EPA-Ghana guideline value of 1 mg/L. Wastewaters with high nutrient levels can cause undesirable phytoplankton growth in the receiving water body. (Hodgson, 2003).

4.2.4 Phosphate-Phosphorus removal

The phosphate-phosphorus concentration of the influent ranged from 3.49 to 5.56 mg/L with an average value of 4.09±0.21 mg/L. The phosphate-phosphorus concentrations of the final effluent were between 1.11 and 1.96 mg/L with an average value of 1.69±0.10 mg/L (Table 3). The mean phosphate-phosphorus removal efficiency was 58.7 per cent (Figure 10) which is averagely appreciably high.

The reduction could be due to the presence of polyphosphate accumulating organisms present in the system. According to Beychok (1971) these micro-organisms can accumulate large quantities of up to 20% their mass of phosphorus in their cells. Microbes utilize phosphorus during cell synthesis and energy transport. As a result, 10 to 30 percent of the influent phosphorus is removed during traditional mechanical/biological treatment (Wenzel and Ekama, 1997; Henze, 1996; Metcalf and Eddy, 1991; Sedlak, 1991). Mulder and Rensink, 1987.The mean phosphate-phosphorus concentration of the final effluent was found to be satisfactory compared to the EPA-Ghana guideline value of 2 mg/L.

4.2.5 Micro-organism removal

Factors that influence coliform removal in both primary facultative and maturation ponds include retention time, temperature, pH and light intensity. The total coliform levels of the raw sewage were between $14x10^7$ to $53x10^7$ counts/100ml with a mean of $296x10^6$ counts/100 ml. The total coliform levels of the final effluent ranged from $18x10^3$ to $2.4x10^6$ counts/100 ml with a mean value of $485x10^3$ (Table 2). The total coliform removal efficiency was 99.93 per cent. The *E. coli* level of the raw sewage ranged from $8x10^7$ to $240x10^7$ counts/100 ml with a mean of $133x10^6$ counts/100 ml, whilst the *E. coli* level of the final effluent ranged from $1x10^3$ to $90x10^3$ counts/100 ml with a mean value of $153x10^3$ count/100 ml (Table 3). The mean *E. coli* removal efficiency was 99.9 per cent (Figure 11) which is significantly high. Most of the total coliform (99.93%) and *E. coli* (99.94%) were removed in the primary facultative pond. Waste stabilization ponds generally give such high micro-organism removal efficiencies. Arceivala (1981) reported that the die-off rate of the micro-organisms was accelerated when pH of the pond water was greater than 9.3. Hodgson & Larmie (1998) showed that there were no coliforms present in final effluent from maturation pond with pH above 10.7. Compared to the EPA-Ghana guideline value of 10 counts/100 ml, the *E. coli* levels of the final effluent was unsatisfactory.

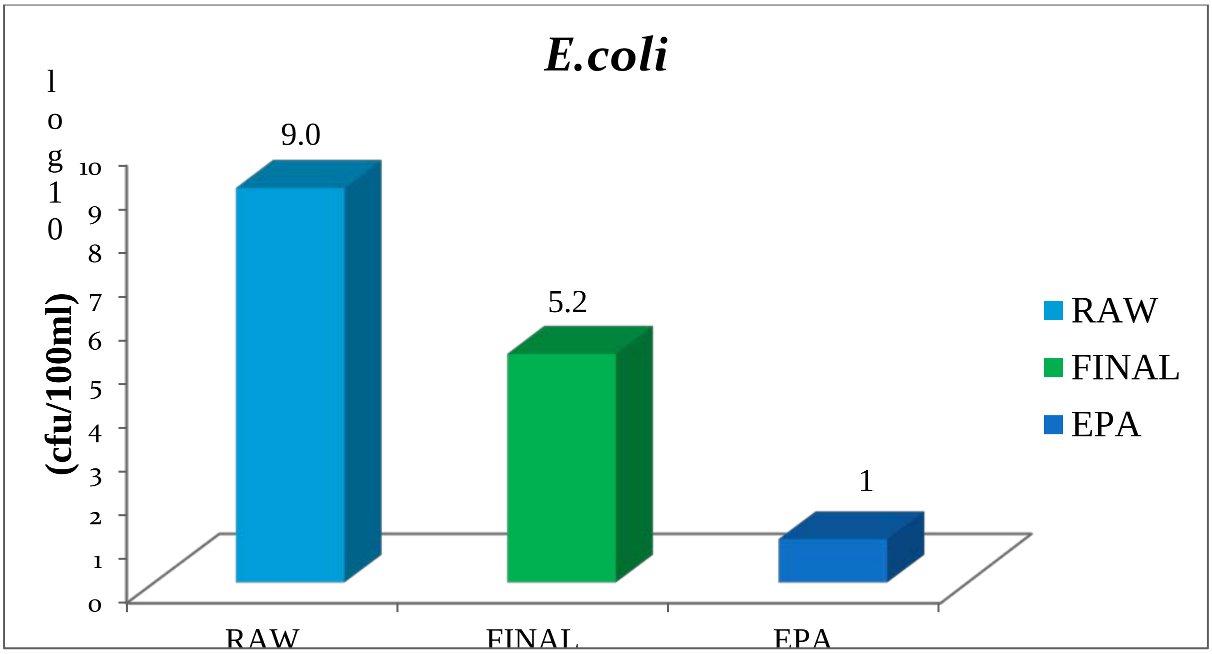

Figure 11: Bacteriological Evaluation of Treatment Plant

At p≤ 0.05, there was a significant difference in the levels of Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia-Nitrogen, Nitrate-Nitrogen, Phosphate, and *E. coli* between influent and effluent samples.

Figure 12 and 13 shows the monthly trend analysis of the influent and effluent discharge from the plant.

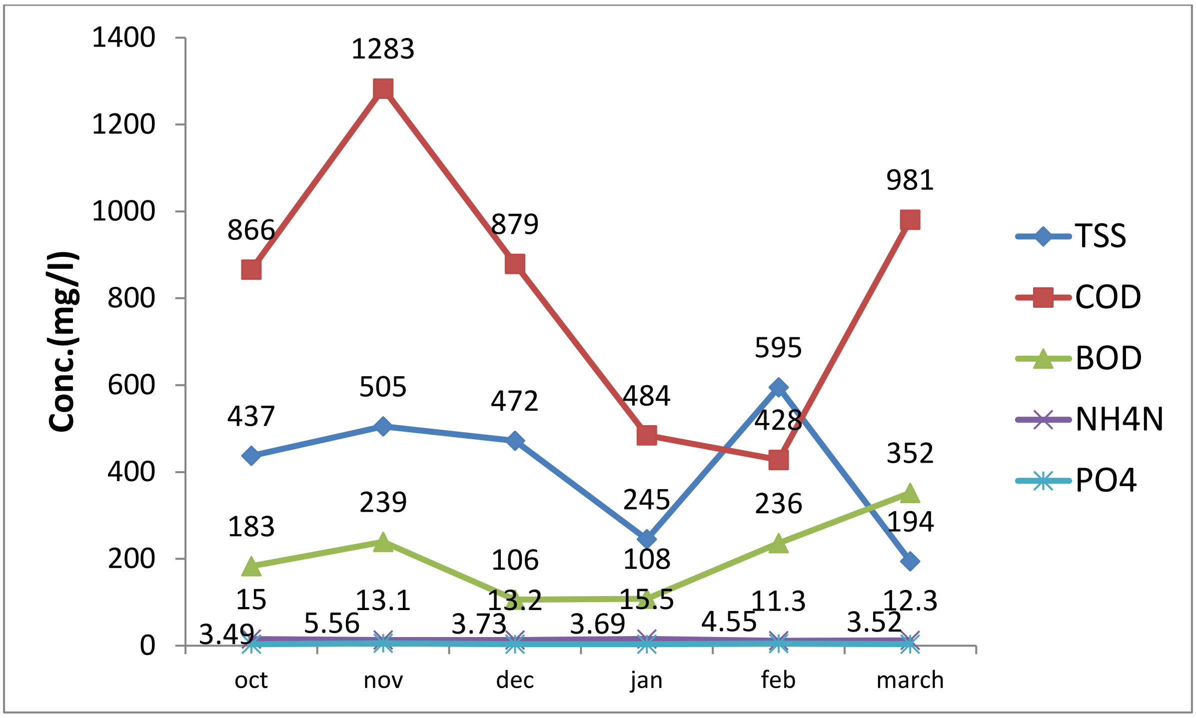

Figure 12: Monthly trend analysis of influent discharge

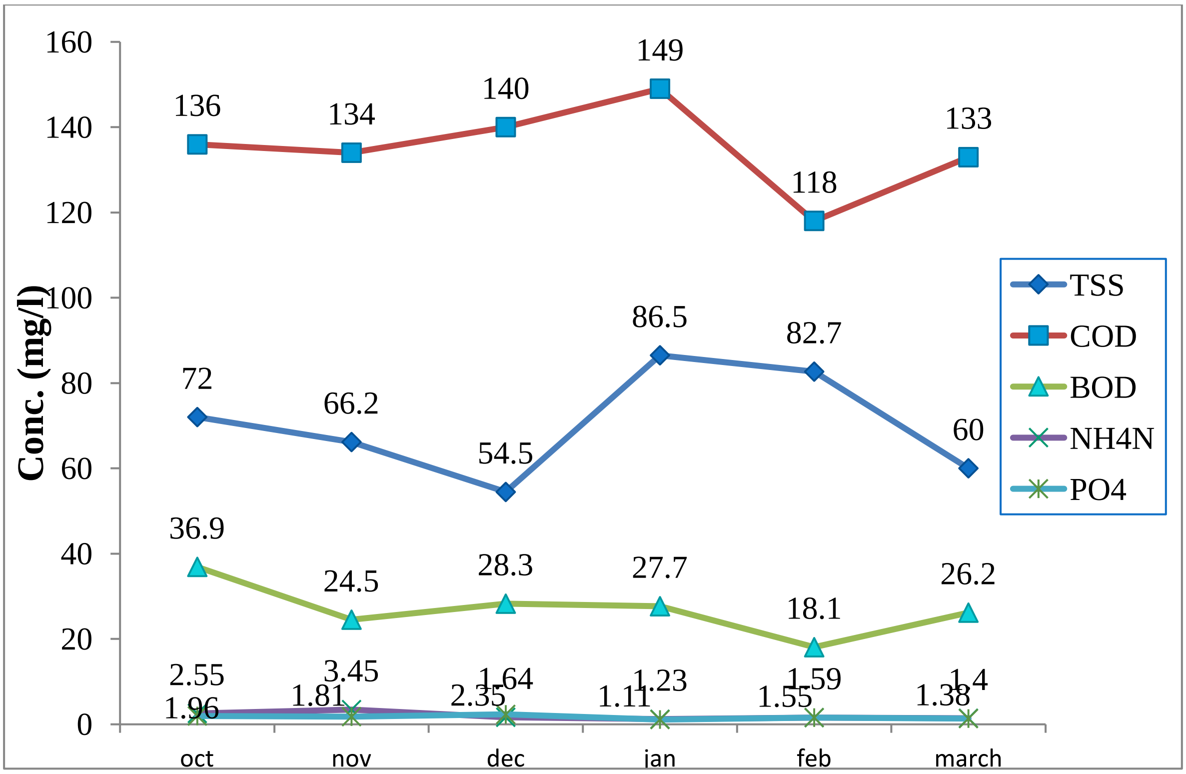

Figure 13: Monthly trend analysis of the plant effluent discharge

4.3 Suitability of treated wastewater for irrigation

Results obtained from the study indicated that the levels of pH (8.3-9.4) electrical conductivity (512-680 µS/cm), total dissolved solids (307 – 405 mg/l), chloride (81.4 – 106 mg/l), iron (1.39 – 1.86 mg/l), ammonia (1.23 – 3.45 mg/l) and phosphate (1.11 – 2.35 mg/l) were within the recommended levels for irrigation purposes. The heavy metals values were generally low. The range of sodium absorption ratio (SAR) (2.62 to 5.05) was satisfactory compared to the recommended value of 3 – 9. Thus, there will be no penetration difficulties when the water is used for irrigation. The sodium absorption ratio (SAR) is used to assess the appropriateness of water for irrigation. The ratio evaluates the degree to which sodium will be adsorbed by the soil. High values of sodium absorption ratio SAR indicate that sodium in the irrigation water may replace the calcium and the magnesium ions in the soil, possibly causing damage to the soil structure.

Table 5: Suitability of Treated Wastewater for Irrigation. (OCT-DEC 2017)

Parameter	Unit	JAN	FEB	MAR	FAO guideline values
PH	pH Units	8.84±0.065	9.38±0.053	8.32±0.445	6.5-9.4
Conductivity	µS/cm	641±2.48	680±3.89	661±1.87	700-3000
Tot. Dis. Solids	mg/l	386±2.83	405±4.32	365±1.96	450-2000
Chloride	mg/l	92.0±0.460	105±2.48	106±0.860	140-350
(SAR)	-	4.62±0.060	4.39±0.070	5.05±0.130	3-9
Ammonia	mg/l	1.23±0.025	1.59±0.004	1.40±0.005	5
Phosphate	mg/l	1.11±0.011	1.55±0.024	1.38±0.003	2
Total Iron	mg/l	1.43±0.039	1.38±0.107	1.46±0.107	5
Manganese	mg/l	0.432±0.036	0.47±0.043	0.489±0.056	0.2
Lead (Pb)	mg/l	0.014±0.004	0.02±0.004	0.015±0.002	-
Chromium (Cr)	mg/l	0.021±0.002	0.01±0.002	0.017±0.003	0.10
Zinc (Zn)	mg/l	0.247±0.041	0.22±0.020	0.205±0.026	1-5
Copper (Cu)	mg/l	0.128±0.0096	0.10±0.007	0.137±0.0098	0.2

Source: FAO water quality guidelines for irrigation (1985)

Table 6 : Suitability of Treated Wastewater for Irrigation. (JAN-MAR 2018)

Parameter	**Unit**	**OCT**	**NOV**	**DEC**	**FAO guideline values**
PH	pH Units	8.84±0.012	7.61±0.049	8.67±0.086	6.5-9.4
Conductivity	µS/cm	512±0.816	560±2.83	625±2.83	700-3000
Tot. Dis. Solids	mg/l	307±1.08	335±1.08	379±3.89	450-2000
Chloride	mg/l	97.5±0.178	94.4±0.141	81.4±0.283	140-350
(SAR)	-	4.92±0.020	2.62±0.009	4.82±0.037	3-9
Ammonia	mg/l	2.55±0.035	3.45±0.028	1.64±0.008	5
Phosphate	mg/l	1.95±0.002	1.81±0.004	2.35±0.008	2
Total Iron	mg/l	1.27±0.046	1.82±0.086	1.72±0.095	5
Manganese	mg/l	0.504±0.116	0.504±0.069	0.524±0.006	0.2
Lead (Pb)	mg/l	0.015±0.004	0.013±0.004	0.018±0.001	-
Chromium (Cr)	mg/l	0.016±0.003	0.019±0.002	0.020±0.003	0.10
Zinc (Zn)	mg/l	0.211±0.017	0.203±0.011	0.226±0.017	1-5
Copper (Cu)	mg/l	0.130±0.0276	0.130±0.0082	0.157±0.0099	0.2

Source: FAO water quality guidelines for irrigation (1985)

4.4 Suitability and sludge quality

This section discusses the results of the study on the concentration of heavy metals and basic nutrients of the sludge in the stream one and stream two ponds of the Accra sewage treatment plant. Variations of heavy metals contents within and between anaerobic, facultative, maturation one and maturation two ponds which are series in connection are all discussed.

4.5.1 Zinc

The study revealed that the Zinc concentration in sludge varied during the study period. Zn in stream-1 anaerobic pond ranged from 12.3 to 80.0 mg/kg with a mean of 64.7±22.0 mg/kg. While in maturation stream-1 pond 2, Zn varied from 63.8 to 137 mg/kg with a mean of 87.8±23.01 mg/kg (Figure 14).

Similarly, Zn in stream-2 anaerobic pond ranged from 62.8 to 82.3 mg/kg with a mean of 69.9±5.65 mg/kg. While in maturation stream-2 pond-2, Zn varied from 32.9 to 46.2 mg/kg with a mean of 39.4±4.58 mg/kg (Figure 15).

Differences in the levels of zinc between the ponds could be attributed to decomposing organic matter, the rate of flow and retention period from one pond to the other. According to Morrison *et al.*, (2004) mean concentrations of Zinc are in the range of 1,600 to 4,100mg/kg. Stabilization of sludge by anaerobic digestion accelerates the biodegradation of organic compounds which could probably have attributed to the difference in Zinc concentrations in anaerobic and maturation ponds as a report by Jensen and Jepsen (2005), on the quality of sewage sludge in Denmark. They found out that Zn concentration was the highest followed by Cu, Pb, Cr, Ni and Cd. Figure 14 shows heavy metals distributions in stream one of the treatment plant.

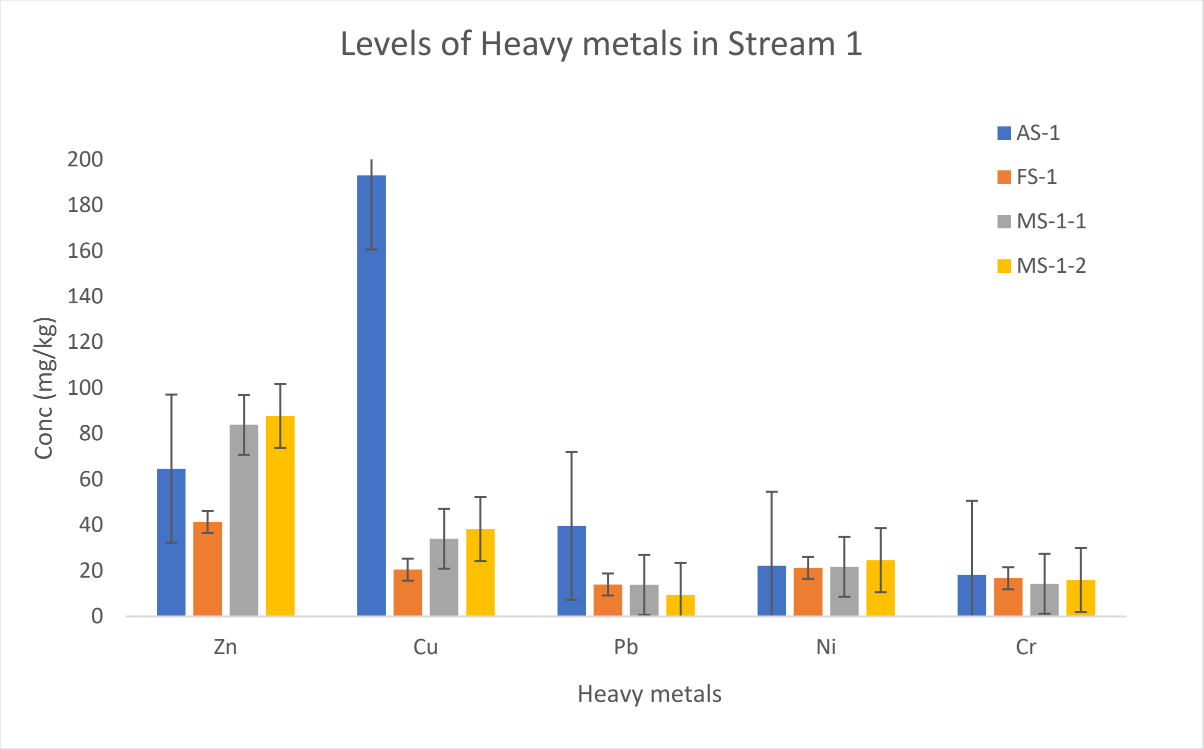

Figure 14: Heavy metals distributions in stream-1 (Zn,Cu,Pb,Ni and Cr)

4.5.2 Copper

Copper concentration in the sludge varied during the study period. Copper in stream-1 anaerobic pond ranged from 169 to 242 mg/kg with a mean 193±24.8 mg/kg. While in maturation stream-1 pond 2, Cu varied from 29.6 to 52.2 mg/kg with a mean of 38.24±7.01 mg/kg (Figure 14). Copper in stream-2 anaerobic pond ranged from 150 to 215 mg/kg with a mean of 188±21.02 mg/kg. While in maturation stream-2 pond-2, Cu varied from 21.9 to 31.6 mg/kg with a mean of 25.7 mg/kg (Figure 15). High levels of Cu in anaerobic ponds could be attributed to the release of heavy metals from decomposing organic sludge. Uptake (adsorption and bioaccumulation) by pond algae and bacterial could cause increase in heavy metal concentration (Shilton, 2005). The heavy metal concentration is directly proportional to heavy metal influent concentrations. A study by Morrison et al., (2004) found mean concentrations of Cu in the range of 245 to 441 mg/kg.

Similarly, a survey by European Protection Agency indicate that mean Cu concentrations are in the range of 115 to 2,580 mg/kg. Also, study done by Bright and Healey, (2003) on four different wastewater treatment plants in Canada reported that Cu had the highest concentration of 1300mg/kg followed by Zn, Pb, Cr, Ni and Cd which is similar to the findings of this study for Zn,>Pb,>Ni > Cr. Figure 15 shows heavy metals distributions in stream two of the treatment plant.

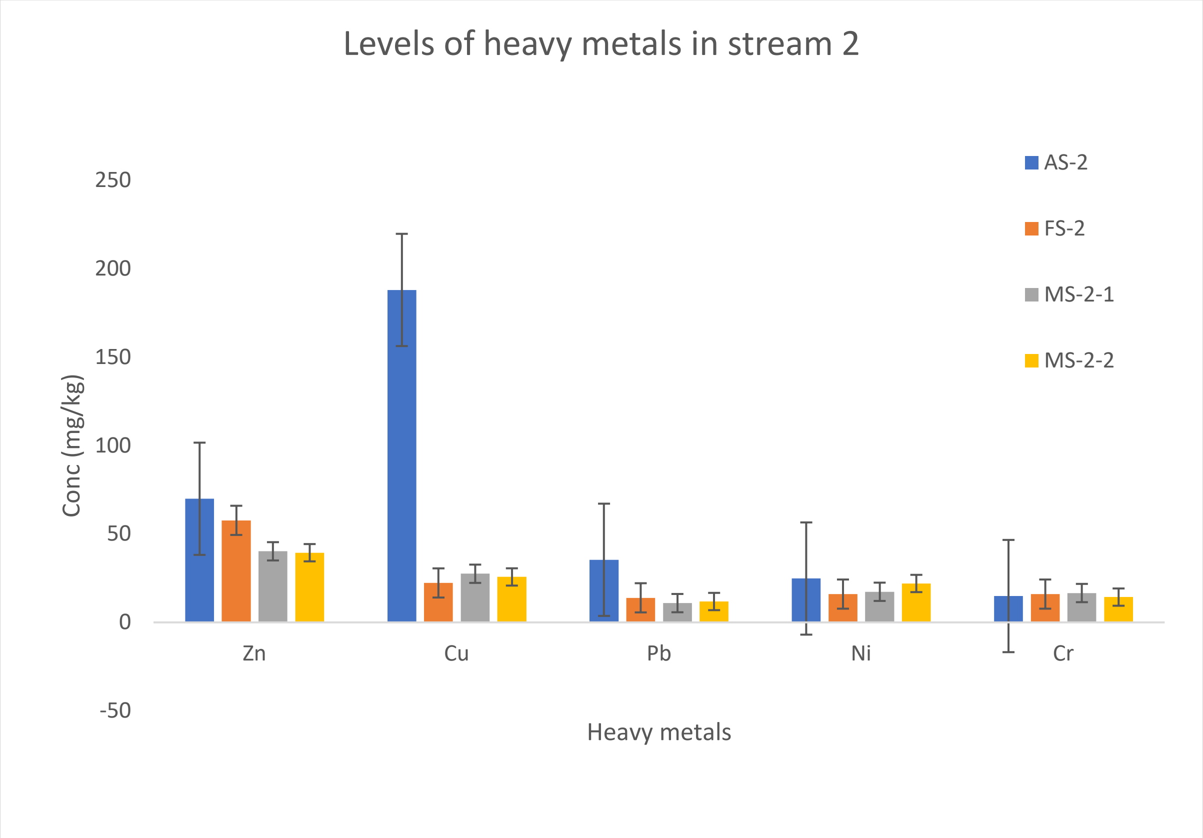

Figure 15: Heavy metals distributions in stream-2 (Zn,Cu,Pb,Ni and Cr)

4.5.3 Lead

Lead concentration in sludge varied during the study period. Lead in stream one anaerobic pond ranged from 33.2 to 49.5 mg/kg with a mean of 39.6±4.7 mg/kg. While in maturation pond 1-2, Lead varied from 5.50 to 18.0 mg/kg with a mean of 9.36±3.8 mg/kg (Figure 14).

Lead in stream-2 anaerobic pond ranged from 28.3 to 40.3 mg/kg with a mean of 35.4±3.49 mg/kg while in maturation pond 2-2, Lead varied from 6.90 to 20.3 mg/kg with a mean of 11.8±4.09mg/kg (Figure 15).

Differences in the levels of lead between the ponds could be attributed to the rate of flow and retention period from one pond to the other. The highest concentration of Lead was recorded in anaerobic pond and the lowest in maturation ponds. This could also be attributed to release of Lead from decomposing organic sludge and pond algae in the chemical forms of Lead. Bioavailability of heavy metals in sludge depends on the chemical form of the metal in sludge where these chemical forms changes during the treatment process at different treatment stages (Karvelas et al., 2003). A survey by European Protection Agency indicates that mean Lead concentrations are in the range of 5.81 to 540 mg/kg. A study by Morrison et al., (2004) found mean concentrations of Lead in the range of 69 to 365 mg/kg.

4.5.4 Nickel

Nickel concentration in the sludge varied during the study period. Ni in stream-1 anaerobic pond ranged from 18.2 to 34.3mg/kg with a mean concentration of 22.2±5.11 mg/kg. While in maturation pond 2, Ni varied from 15.1 to 58.8 mg/kg with a mean concentration of 24.6±14.2 mg/kg (Figure 14).

Nickel in stream-2 anaerobic pond ranged from 15.8 to 58.8 mg/kg with a mean concentration of 24.8±14.1 mg/kg. While in maturation pond 2-2, Ni varied from 18.6 to 26.2 mg/kg with a mean concentration of 22.0±2.33 mg/kg (Figure 15). Nickel is very easily extracted from soils and sludge by plants (Dennis *et al.,* 2003).

There was not much difference in the levels of Nickel in all the ponds this could be attributed to the easy release of Nickel from decomposing organic sludge in anaerobic ponds to the various ponds. Also, presence of algae and other vegetation in maturation ponds which accumulate heavy metals may have released it. The high level of Nickel in anaerobic pond could probably be attributed to variations in the incoming wastewater composition which determine the characteristics of the sludge produced.

4.5.5 Chromium

Chromium concentration in sludge varied during the study period. Cr in stream one anaerobic pond ranged from13.9 to 22.7 mg/kg with a mean value of 18.2±2.96 mg/kg while in maturation pond 2, Cr varied from 13.0 to 25.8 mg/kg and a mean value of 15.9±4.2 mg/kg (Figure 14). Chromium in stream-2 anaerobic pond ranged from 10.2 to 24.0 mg/kg with a mean concentration of 14.9±4.2 mg/kg.

While in maturation pond 2-2, Cr varied from 12.0 to 17.3 mg/kg with a mean value of 14.3±1.67 mg/kg (Figure 15). The highest mean value of chromium was recorded in the anaerobic pond while the lowest mean value was recorded in the maturation pond. This could be attributed to release of Cr from decomposing organic sludge in anaerobic ponds. Changes in the incoming wastewater composition could probably have contributed to the variations in the levels of Cr between the ponds. According to Dennis *et al.,* 2003, only a small part of the chromium that ends up in water will eventually dissolve.

4.5.6 Cadmium

Cadmium concentration in sludge varied during the study period. Cadmium in stream one anaerobic pond ranged from 0.500 to 0.744 mg/kg with a mean value of 0.610±0.075 mg/kg. While in maturation pond 1- 2, Cadmium varied from 0.264 to 0.439 mg/kg with a mean value of **0.352±0.05** mg/kg (Figure 16). Cadmium in stream-2 anaerobic pond ranged from 0.416 to 0.748 mg/kg with a mean concentration of 0.592±0.112 mg/kg. While in maturation pond 2-2 Cadmium varied from 0.215 to 0.459 mg/kg with a mean concentration of 0.327±0.07 mg/kg (Figure 17).

Differences in the levels of cadmium between the ponds could be attributed to the rate of flow and retention period from one pond to the other. Most heavy metals in wastewater are associated with particulate matter and are deposited in wastewater sludge. This could probably be the cause of high values of Cadmium in anaerobic pond. Similarly, variations in the levels of Cadmium between the ponds could probably be attributed to the variations in incoming wastewater composition. A study by Morrison *et al.,* 2004 found mean concentration of Cadmium was 1.90 mg/kg. High values could be as a result of direct discharge from industrial operations,

4.5.7 Arsenic

Arsenic concentration in the sludge varied during the study period. Arsenic in stream-1 anaerobic pond ranged from 0.292 to 0.798 mg/kg with a mean value of 0.492±0.21 mg/kg while in maturation pond 2, Arsenic varied from 0.257 to 0.398 mg/kg with a mean value of 0.310±0.052 mg/kg (Figure 16). Arsenic in stream-2 anaerobic pond ranged from 0.142 to 0.897 mg/kg with a mean concentration of 0.548±0.24 mg/kg. While in maturation pond 2-2 Arsenic varied from 0.115 to 0.216 mg/kg with a mean concentration of 0.165±0.03 mg/kg (Figure 17). The highest mean value of Arsenic was recorded in anaerobic pond while the lowest mean value was recorded in maturation pond. This could be attributed to release of Arsenic from decomposing organic sludge in anaerobic ponds. Changes in the incoming wastewater composition could probably have contributed to the variations in the levels of Arsenic between the ponds. Figures 16 and 17 show heavy metals distributions in stream one and stream two of the treatment plant.

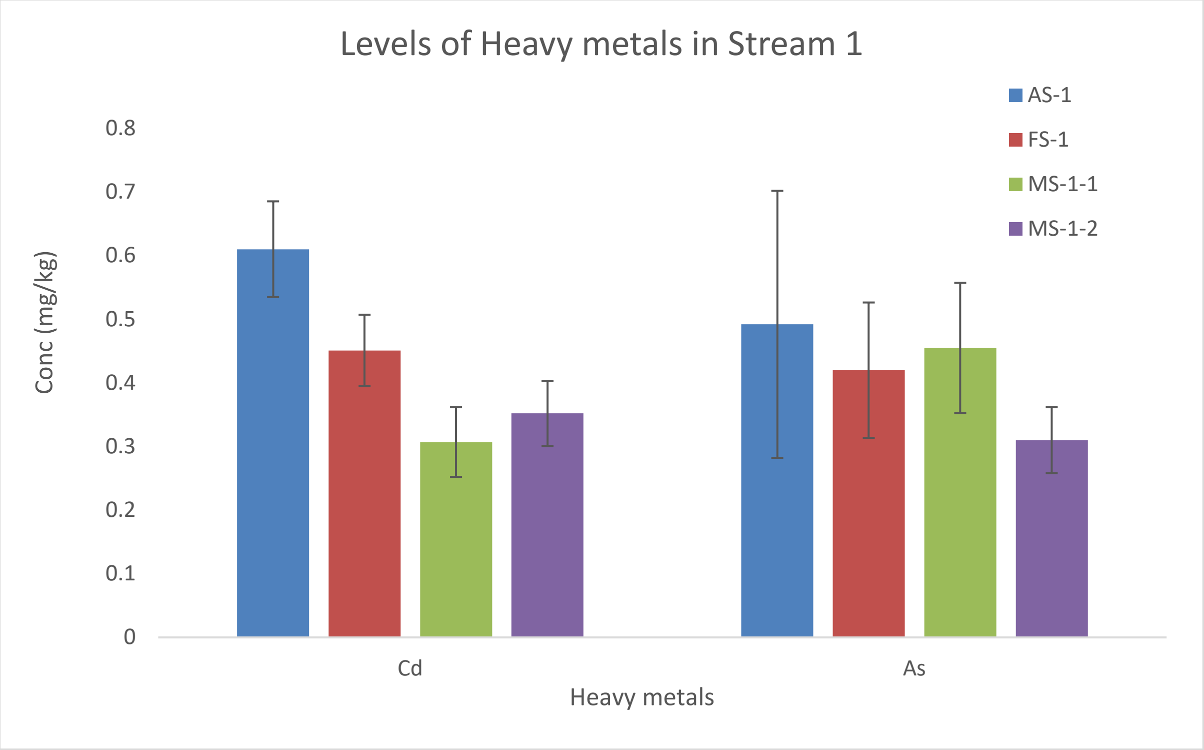

Figure 16: Heavy metals distributions in stream-1(Cd and As)

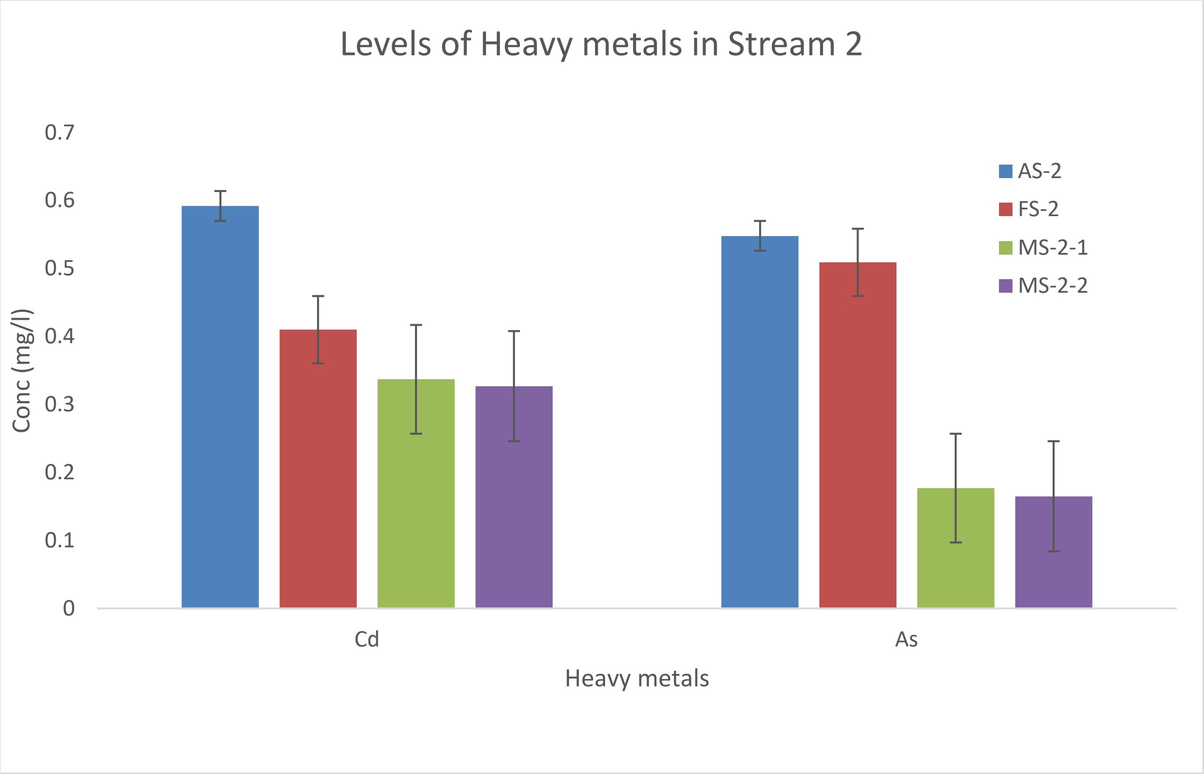

Figure 17: Heavy metals distributions in stream-2(Cd and As)

4.5.8 The heavy metal content

The metal content in the sludge from the WSP will be discussed in terms of the different sludge types at the plant, in comparison to sludge from other treatment plants.

Different sludge types at the Accra sewage treatment plant WSP

Differences in metal concentrations can be seen both between the stream one and stream two individual ponds types of sludge, but there wasn’t a significant difference between the two main stream sludge quality types. From both analysis, anaerobic stream one pond and anaerobic stream two pond sludge has the highest heavy metal content and the sludge with the lowest content of heavy metals reduces through the facultative and maturation ponds for both streams. According to the results in this study, the anaerobic sludge has in most of the cases higher concentrations of heavy metals in comparison to the facultative and the maturation sludge. According to Oliver & Cosgrove (1974), the heavy metals in insoluble form or adsorbed to particles are most likely to be separated in the primary treatment to the primary sludge, whilst heavy metals appearing in soluble form are mostly removed in the secondary treatment step to the secondary sludge. If it is assumed that the incoming wastewater to the WSP contains metals in both soluble and insoluble form and adsorbed to particles, it can be seen that most of the incoming metals therefore are in the insoluble form. According to this study, the facultative and maturation sludge is more favourable to use as organic compost manure than the anaerobic sludge in terms of metal content. However, the levels in the anaerobic sludge are within the threshold of the sludge quality guidelines values.

4.5.9 Comparison to sludge from other WWTPs

A study by Ofori-Amanfo D., *et al*, 2018, the study revealed that sun-drying of dewatered faecal sludge is an effective means of reduction the pathogens and other toxic compounds found in raw sewage sludge. Dewatered faecal sludge from the Lavender Hill Faecal Treatment Plant recorded an average mean value of 4x107 egg/20g and 4x104 cfu/g, indicating helminth egg and faecal coliform respectively. The final Dry Faecal Sludge had a better nutrient balance (N, P, K OM) with reduce content of pathogens (faecal coliform, E. coli and Helminth egg) and metal concentrations although the content of pathogens found after treatment were still higher compared to required legislation.

The concentrations of metals analysed in dried faecal sludge, compost and formulated mix were too low to be source of concern when the biosolids are to be considered as soil amendment. When comparing the heavy metal content in the sludge from the WSP with the sludge types from other WWTPs, it is difficult to determine and assess clear differences. A clear trend in sludge quality from different treatment processes cannot be established. However, the impact of stormwater could be interesting to analyze when looking at the comparison between sludge from different WWTPs since it could be a contributing factor to levels in sludge. The Accra sewage treatment plant is a sewer system consists of combined pipe systems, allowing stormwater and runoff from roads with influence from urban activities and traffic to enter the pipe system together with wastewater. This water could be heavily polluted and might contain high concentrations of heavy metals. The presence of high amounts of heavy metals in faecal/sewage sludge is one of the most significant reasons that potentially limit its application in agricultural usefulness.

The essence of measuring trace metals levels in the sludge was to give one an idea of the state of the sludge and their possible use in Agriculture. The trace metals analysed included both essential and non-essential metals. The essential metals (Zn, Cu, Cr, and Ni) are required in minute concentrations for various metabolic activities by humans and animals in the ecological procedures. At high concentrations, the essential metals can also be toxic. The non-essential metals (Cd, Pb and As) on the other hand are toxic and are not required by both humans and animals. According to Akrivos *et al.*, (2000), heavy metals may be divided into two groups: (a) zinc, copper, nickel and chromium that are phytotoxic and can affect crop growth and (b) lead, cadmium, mercury and molybdenum that are normally not toxic to plants but may be harmful to animals that ingest the treated crop.

Trace metals concentrations in the sludge from the various sampling points were generally low; compared to the Limits for metals brought to agriculture land by sewage sludge in South Africa (SFS, 1998:944; Water Research Commission, 1997) Table 7: Mean values of heavy metal concentrations (mg/kg) in stream-1 and stream -2

4.6 Chemical characteristics of sludge from Accra sewage treatment plant

Table 7: Mean values of heavy metal concentrations (mg/kg) in stream-1 and stream -2

SAMPLE ID	Zn	Cu	Pb	Cd	Ni	Cr	As
Stream-1 Anaerobic	64.7±22.0	193±24.8	39.6±4.7	0.610±0.075	22.2±5.11	18.2±2.96	0.492±0.21
Stream-1 Facultative	41.3±17.78	20.5±4.24	14.7±4.99	0.451±0.056	21.2±8.6	16.7±7.0	0.420±0.106
Stream-1 Maturation-1	83.9±19.3	34.0±5.9	13.8±4.7	0.307±0.055	21.7±9.0	14.3±3.5	0.455±0.102
Stream-1 Maturation-2	87.8±23.01	38.2±7.01	9.36±3.8	0.352±0.05	24.6±14.2	15.9±4.2	0.310±0.052
Stream-2 Anaerobic	69.9±5.65	188±21.02	35.4±3.49	0.592±0.112	24.8±14.1	14.9±4.2	0.548±0.24
Stream-2 Facultative	57.7±12.5	22.3±2.72	13.9±3.99	0.415±0.071	16.0±9.18	16.0±4.71	0.509±0.198
Stream-2Maturation-1	40.2±8.04	27.5±5.92	10.9±3.60	0.337±0.051	17.3±9.61	16.6±2.71	0.177±0.04
Stream-2 Maturation-2	39.4±4.58	63±3.51	11.8±4.09	0.327±0.07	22.0±2.33	14.3±1.67	0.165±0.03
Limits South Africa	**200**	**50.5**	**50.5**	**15.7**	**200**	**1750**	**15**

4.6.1 Basic nutrients mean values are shown in tables: 8-11.

Table 8: Mean Nutrients levels in stream-1 and 2 anaerobic ponds

Parameters		Mean (AS1)	Mean (AS2)
pH (H_2O) (1:2.5)		6.8±0.14	6.6±0.28
Electrical Conductivity (µS/cm)		1194±50.07	1309±55.5
Total Nitrogen (mg/kg)		17783.33±813.136	17366.67±1118.247
OC %		20.7±0.95	20.2±1.32
OM %		35.5±1.65	34.7±2.26
Total. Phos (mg/kg)		382±20.89	363±22.93
Avail.Phos (mg/kg)		9.75±0.48	9.67±0.55
Total.Potas (mg/kg)		209±1.98	205±3.69
Avail.Potas (mg/kg)		8.35±0.29	8.51±0.25
Exchangeable Cation (Cmol(+)/ kg)	K	0.260±0.01	0.230±0.04
	Na	0.540±0.02	0.530±0.04
	Ca	41.1±1.75	40.3±2.83
	Mg	6.75±0.55	6.79±0.52

Table 9: Mean nutrients Levels in stream-1 and 2 facultative ponds

Parameters		Mean (FS1)	Mean (FS2)
pH (H_2O) (1:2.5)		7.3±0.50	7.1±0.58
Electrical Conductivity (µS/cm)		1438±20.37	1575±81.70
Nitrogen (mg/kg)		13008.33±717.345	12508.33±417.832
OC %		14.7±1.08	13.4±2.05
OM %		25.3±1.87	23.0±3.51
Total. Phos(mg/kg)		336±21.60	315±29.050
Avail.Phos (mg/kg)		7.52±0.24	7.65±0.17
Total.Potas (mg/kg)		188±6.54	186±4.25
Avail.Potas (mg/kg)		7.86±0.27	7.38±0.26
Exchangeable Cation (Cmol(+)/ kg)	K	0.19±0.03	0.189±0.05
	Na	0.41±0.04	0.45±0.039
	Ca	36.7±1.78	36.8±1.86
	Mg	6.02±0.56	5.94±0.33

Table 10: Mean nutrients Levels in stream-1 and 2 maturation ponds

Parameters		Mean (MS1-1)	Mean (MS2-1)
pH (H_2O) (1:2.5)		7.5±0.51	7.4±0.38
Electrical Conductivity µS/cm		1470±28.41	2465±88.59
Total Nitrogen (mg/kg)		6648.333±324.936	4226.667±332.347
OC %		7.15±1.12	4.82±0.56
OM %		12.3±1.92	8.29±0.97
Total. Phos(mg/kg)		290±30.86	219±13.08
Avail.Phos (mg/kg)		5.47±0.19	4.18±0.23
Total.Potas (mg/kg)		169±4.97	157±2.91
Avail.Potas (mg/kg)		6.78±0.18	6.25±0.21
Exchangeable Cation (Cmol (+)/ kg)	K	0.23±0.01	0.54±0.01
	Na	0.79±0.05	1.57±0.07
	Ca	34.8±5.44	21.8±1.42
	Mg	5.6±0.41	5.25±0.54

Table 11: Mean nutrients Levels in stream-1 and 2 maturation ponds

Parameters		Mean (MS1-2)	Mean (MS2-2)
pH (H_2O) (1:2.5)		7.28±0.30	7.48±0.41
Electrical Conductivity(µS/cm)		1619±48.46	2419±32.82
Total Nitrogen (mg/kg)		6077.5±351	4496.667±593
OC %		6.68±1.05	5.18±0.70
OM %		11.5±1.79	8.99±1.18
Total. Phos(mg/kg)		279±25.21	223±14.98
Avail.Phos (mg/kg)		5.09±0.41	4.12±0.19
Total.Potas (mg/kg)		165±2.09	154±2.35
Avail.Potas (mg/kg)		6.40±0.18	6.10±0.33
Exchangeable Cation (Cmol(+)/ kg)	K	0.280±0.05	0.500±0.01
	Na	0.800±0.05	1.60±0.05
	Ca	33.5±6.7	22.2±2.06
	Mg	5.68±0.31	5.35±0.55

Table 12: Basic nutrients interpretation guide for total nitrogen, total phosphorus and total potassium levels

	Acceptable thresholds (mg/kg)			
PARAMETER		Low	Medium	high
Total nitrogen(mg/kg)		500-1500	1500-2500	2500-5000
Total phosphorus(mg/kg)		<20	20-40	40-100
Total potassium(mg/kg)		<150	150-250	250-280

Source: Apal Soil quality interpretation guide (2019)

4.6.2 Total Nitrogen

The data shows that the sludge presents a good source of primary macro nutrient for soil amendment with substantial amount of total nitrogen, total phosphorus and total potassium. The total nitrogen concentration in the sludge varied during the study period. Total nitrogen in stream one anaerobic pond ranged from 16800 to 19000 mg/kg with a mean concentration of 17783±813.136 mg/kg, whereas in maturation pond 1-2 total nitrogen varied from 3700 to 6600 mg/kg with a mean concentration of 6077.5±351.057 mg/kg. Similarly, there was a variation in the stream two ponds. Total nitrogen in stream two anaerobic pond ranged from 15000 to 19000 mg/kg with a mean concentration of 17366.67±1118.247 mg/kg. While in maturation pond 2-2, total nitrogen varied from 3200 to 5100 mg/kg with a mean concentration of 4496.667±593.499 mg/kg (table 8.0-11).

4.6.3 Total Phosphorus

The total phosphorus level in stream one anaerobic pond ranged from 350 to 410 mg/kg with a mean value of 382±20.89 mg/kg. While in maturation pond 1-2 total phosphorus varied from 260 to 340 mg/kg with a mean concentration of 279±25.21 mg/kg. Similarly, total phosphorus in stream-2 anaerobic pond ranged from 330 to 390 mg/kg with a mean concentration of

363±22.93 mg/kg. While in maturation pond 2-2 total phosphorus varied from 200 to 250 mg/kg with a mean concentration of 223±14.98 mg/kg (table 8.0-11).

4.6.4 Total Potassium

The total potassium in stream one anaerobic pond ranged from 206 to 212 mg/kg with a mean of 209±1.98 mg/kg. While in maturation pond 1-2 total potassium varied from 162 to 169 mg/kg with a mean value of 165±2.09 mg/kg. Total potassium in stream two anaerobic pond ranged from 202 to 211 mg/kg with a mean value 205±3.690 mg/kg. While in maturation pond 2-2 total potassium varied from 150 to 158 mg/kg with a mean concentration of 154±2.35 mg/kg (Table 8.0-11).

4.6.5 The Sludge nutrient content

The nutrient value of the sludge from the sewage treatment plant is discussed in terms of the different sludge types at stream one and stream two ponds.

4.6.6 Total nitrogen

The nitrogen content in the different sludge types is more similar and that could probably be explained by the fact that the processes in the treatment plants are quite similar regarding nitrogen separation because, the process is natural and biological one. The nitrogen levels are high and it could be attributed to the design which provides long period for desludge to be done every five years. Since its construction in the year 2012 the sludge analysis was done in October 2017 to March.2018

4.6.7 Total phosphorus

A reason for the higher phosphorus value result in the sludge from sewage treatment plant could probably be due to the communities the treatment plant serves. The plant is within the catchment area of the University of Ghana, Presbyterian Boys Senior High School, University of Professional Studies, Achimota Senior High School and currently the Achimota Hospital of which their daily usage of soaps and detergents are high and it is discharge into the WSP for treatment. All these settles on the sludge hence the high levels of total phosphorus. The phosphorus is assumed to be removed in the maturation ponds and can therefore be recovered in the sludge. However, this is not the case in both stream one and stream two ponds.

4.6.8 Total Potassium

The potassium content as well as nitrogen is also quite similar between the different sludge types in this comparison. This could also be attributed to similar reason of the total phosphorus as the WSP serves schools community with laboratories where potassium compounds are used often in practical lessons making its more likely to expect this high level in the sludge.

Different sludge types at WSP

The result of the sludge analysis indicates that the nutrient value of the sludge differs along the individual ponds but it is similar at the two streams. This could be so because the wastewater goes through the same treatment processes at WSP. The nutrient content seen in Table 8-11 shows that the anaerobic pond sludge has the highest nutrient value. The fact that the anaerobic sludge shows higher contents of nutrients than the facultative and maturation ponds sludge, agrees with Naturvårdsverket (2008), saying that nutrients are more likely to be removed with the secondary pond sludge than the primary sludge, due to the natural process of treatment.

Comparison with sludge from other WWTPs

From the comparative analysis with other WWTPs it can be seen that the nutrient from WSP treatment plant generally shows lower nutrient content in comparison to the sludge types from other WWTPs. A reason for the lower phosphorous value result in the sludge from WSP could probably be due to the differences in treatment processes at the other plants. At some treatment plant the decomposing period is not long enough for the sludge to break done while with the WSP the removal is done by natural and biological process. The phosphorous is assumed to be removed in the maturation ponds and can therefore not be recovered in the sludge. This is however not the case for the other treatment plants from the comparison.

The nitrogen content in the different sludge types are low similar to that of phosphorus and that could probably be explained by the same fact that the processes in the treatment plants are different process as removal is done by natural biological process. However, the nitrogen content in the studies on WSP is higher in terms of required range (**Apal Soil quality interpretation guide)**. There could also be a lot of other reasons explaining this difference, like the long build-up of the sludge over five years period.

The potassium content is as well as nitrogen also quite similar between the different sludge types in this comparison. This could be explained by Ngole *et al.* (2006) saying that potassium is more likely to be separated to the liquid stream than to the sludge. It is therefore hard to separate potassium to the solid phase, independent on the treatment processes used.

Stabilized sewage sludge means that, easily degradable organic material is degraded by microorganisms. Sewage sludge contains a lot of organic material, which can be beneficial for plants, or can be a contaminant in surface water. Stabilized sludge is more predictable, smells less, and contains nutrients that are in a form plants and microorganisms in the soil can readily use.

Nutrient management: Sludge contains nutrients, like nitrogen, potassium, and phosphorous. These nutrients are needed for plant growth. Farmers apply them to increase crop yield. However, these nutrients can also infiltrate through soil into groundwater, or may be transported by rainwater runoff to surface water bodies. They can contaminate both drinking water and the environment.

Nutrient management generally means changing the form of nutrients (for example, from liquid to solid, or from organic to inorganic). Nutrients are not necessarily removed during treatment, but transformed. When organic material is stabilized, nutrients are also stabilized (meaning they are taken up and incorporated into organic material).

The form of the nutrient is important for managing the sludge and protecting the environment. For example, nitrogen in an organic form (for example, compost) is stable and slowly released. It can be directly applied to crops and beneficially used. Whereas nitrogen in an inorganic or ionic form (for example, nitrogen found in leachate) can have negative impacts. For example, it could harm plants when applied directly, move down through the soil to groundwater, or volatilize into the environment and cause harm. The levels obtained from the study indicate that the sludge is highly rich in nutrients which will be generally favourable for organic compost. Figure 18 and 19 show the basic nutrients of total nitrogen, total phosphorous and total potassium distributions in the various ponds of the treatment plant.

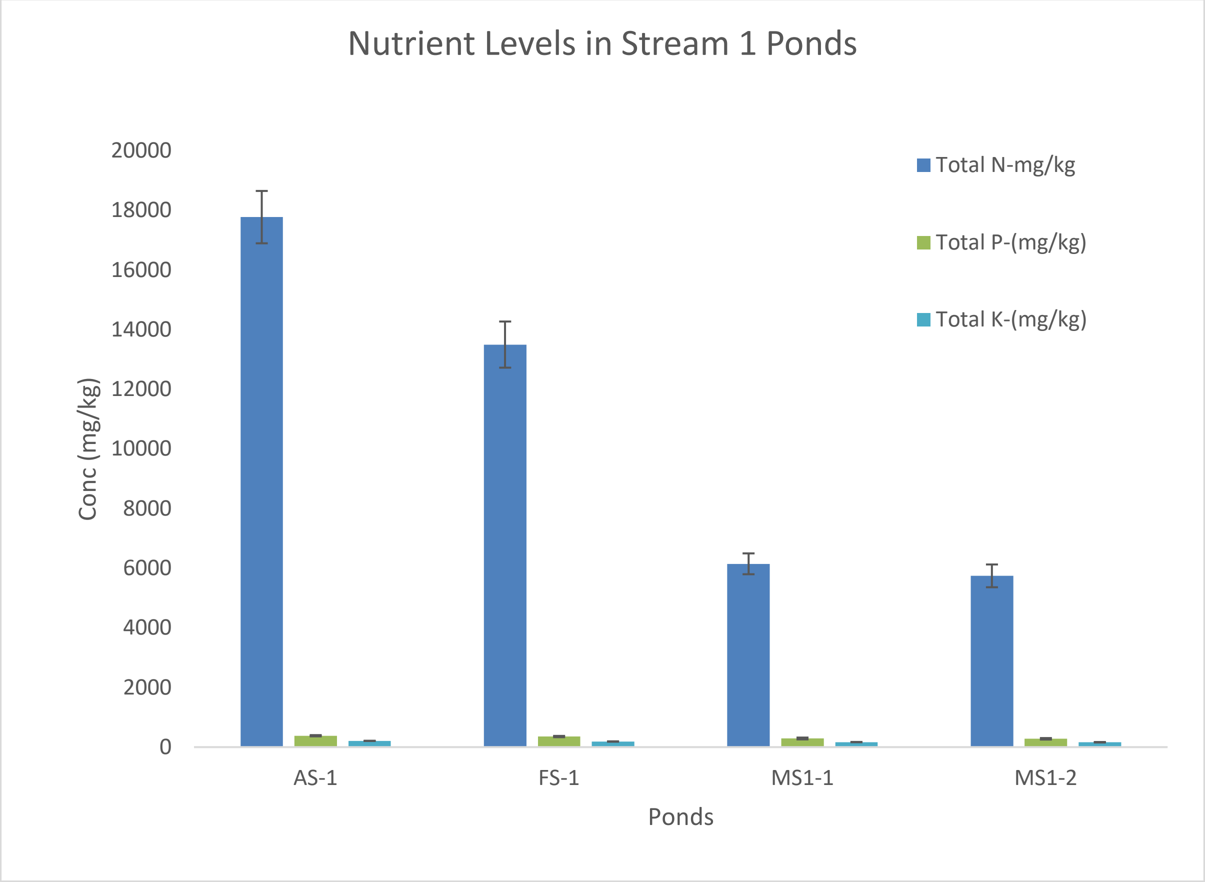

Figure 18: Mean values of Basic nutrients of sludge in stream-1 WSP

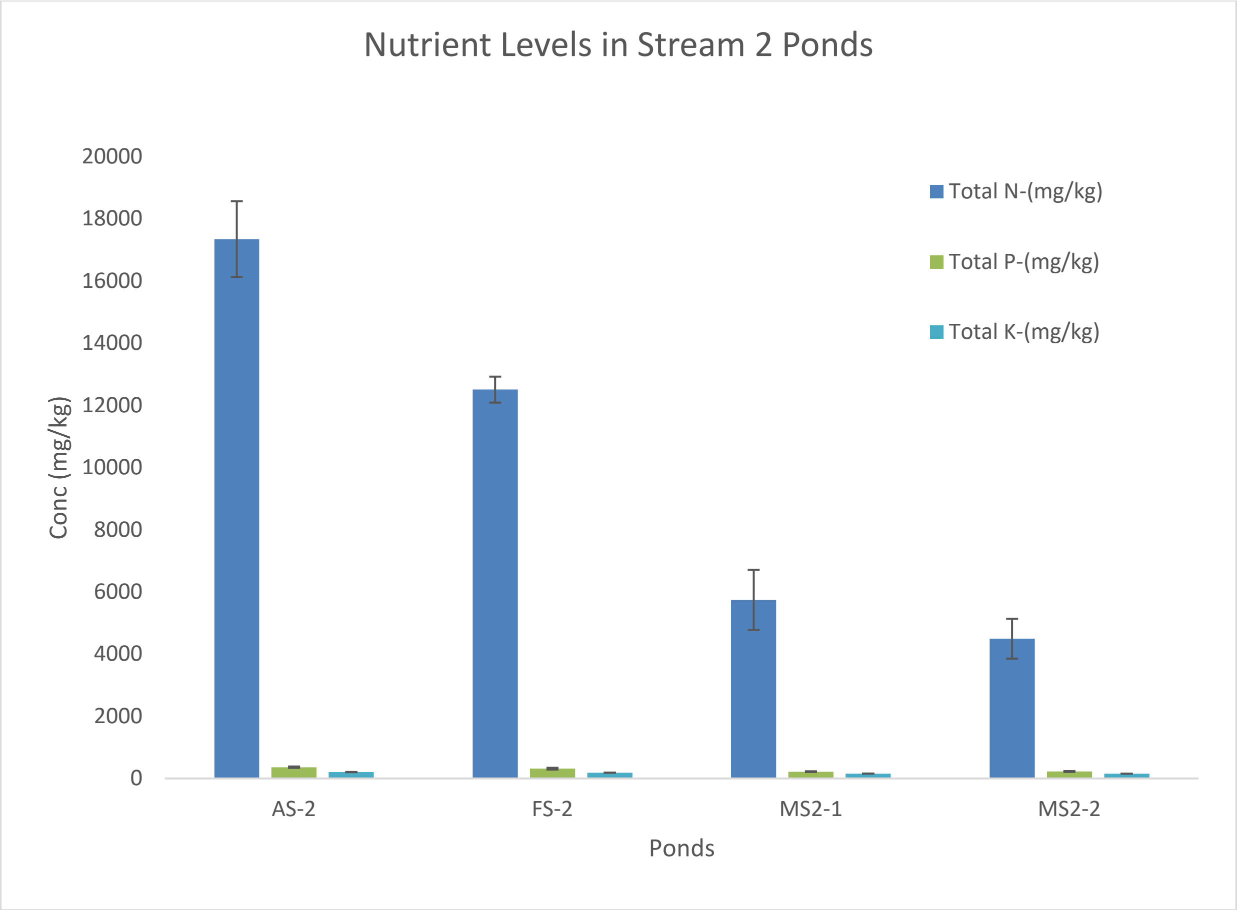

Figure 19: Mean values of Basic nutrients of sludge in stream-2 WSP

4.6.9 Levels of pH and conductivity in the sludge.

pH is the negative logarithm of the active hydrogen ion (H+) concentration in the soil solution. It is the measure of soil acidity and neutrality. It is simple but very important estimation for soils as soil pH has a considerable influence on the availability of nutrients to crops. It also affects microbial population in soils. Most nutrient elements are available in the pH range of 5.5–6.5. pH in stream one anaerobic pond ranged from 6.5 to 7.0 with a mean of 6.8. (Guide to laboratory establishment for plant nutrient analysis) by Motsara and Roy (2008). pH in stream one anaerobic pond ranged from 6.5 to 7.0 with a mean of 6.8). In facultative pond 1, pH ranged from 6.5 to 7.8 with a mean of 7.3. In maturation pond 1-1, pH ranged from 6.6 to 8.1 with a mean of 7.5. In maturation pond 1-2 pH varied from 6.8 to 7.6 with a mean of 7.3. Similarly, there was a variation in the stream two ponds. pH in stream two anaerobic pond ranged from 6.0 to 6.9 with a mean of 6.6. In facultative pond, pH ranged from 6.1 to 7.9 with a mean of 7.1. In maturation pond 2-1, pH ranged from 6.8 to 7.9 with a mean of 7.4. In maturation pond 2-2, pH varied from 6.8 to 7.9 with a mean of 7.5. (Table 8-11)

Table 13: Physicochemical interpretation guide for pH values

	Acceptable thresholds (pH Unit)			
PARAMETER		Slightly acidic	Slightly Alkaline	Moderately alkaline
pH (H_2O) (1:2.5)		6.5-6.9	7.1-7.5	7.6-8.3

Source: Apal Soil quality interpretation guide (2019)

Conductivity is an indicator of plant growth, microbial activity, and salt tolerance (Guide to laboratory establishment for plant nutrient analysis) by Motsara and Roy (2008). Conductivity stream one anaerobic pond ranged from 1126 to 1184(µS/cm) with a mean of 1194(µS/cm) conductivity in the facultative pond 1 ranged from 1415 to 1470(µS/cm) with a mean of 1438 (µS/cm) in the maturation pond 1-1 it ranged from 1422 to 1520 (µS/cm) with a mean of 1470 (µS/cm). Conductivity varied from maturation pond range from 1-2 1565 to 1716(µS/cm) with a mean of 1620(µS/cm) (Table 8.0-11).

Similarly, there was no variations in stream two. Conductivity in stream two anaerobic pond ranged from 1240 to 1595(µS/cm) with a mean of 1343(µS/cm). Conductivity in stream two facultative pond ranged from 1508 to 1765(µS/cm) with a mean of 1575(µS/cm) Conductivity In maturation pond 2-1 ranged from 2389 to 2670(µS/cm) with a mean concentration of 2465(µS/cm). In maturation pond 2-2 Conductivity in maturation pond2-2 ranged from 2360 to 2469(µS/cm) with a mean value of 2420(µS/cm). (Table 7.0-10). Differences in the levels of pH and conductivity between the ponds could be attributed to the designed functions of the ponds. The pH in the anaerobic ponds are slightly acidic because there is no oxygen in the ponds which eventually affects the sludge quality whiles the facultative and the maturation ponds are slightly alkaline because the ponds are oxygenated ponds and it improves the sludge quality. These trends were also established in the conductivity values.

pH levels of the sludge from the various sampling points were generally acceptable; compared to the Apal Soil quality interpretation guide (2019).

4.7 Organic carbon content

Organic carbon ranged from 4.86- 20.7% in the ponds and it is sufficient to reduce the deficit of organic matter in the soil. The ratio 12:1 of carbon to nitrogen (C: N) is good. The sludge used in the research is a stable source of organic matter.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.0 Major findings

The major findings of the study are summarised in Table 14. This is followed by the conclusions established in the study and recommendations made.

Table 14: Summary of major findings

Objectives of the study	**Achievements of the study**
To analyse both physiochemical and bacteriological parameters of the influent and effluent to assess the performance efficiency of the plant.	The performance assessment showed that the WSP achieved high removal of organic matter, nutrients and *E. coli*. Even though removal efficiency of *E. coli* is high, it did not meet the acceptable standard. Arceivala (1981) reported that the die-off rate of the micro-organisms was accelerated when pH of the pond water was greater than 9.3. Hodgson & Larmie (1998) showed that there were no coliforms present in final effluent from maturation pond with pH above 10.7.
To assess the physiochemical effluent quality of the treated effluent for irrigational purposes.	The physicochemical characteristics of the treated effluent were within FAO recommended levels/standards for irrigation purposes.

To determine the quality characteristics of the sludge for organic compost (manure).	Trace metals concentrations in the sludge from the various sampling points were generally within the threshold of the guidelines value. Organic carbon ranged from 4.86-20.7% in the ponds and it is sufficient to reduce the deficit of organic matter in the soil. The ratio 12:1 of carbon to nitrogen C: N is acceptable. Native or uncultivated soils have approximately 12 parts of carbon to each part of nitrogen, or a C:N ratio of 12:1.

5.1 Conclusions

The following conclusions were drawn from the study on the sewage treatment ponds at Legon campus: The treated effluent from the waste stabilisation ponds at Accra sewage treatment plant met both the environmental and health criteria set by the Ghana Environmental Protection Agency (GEPA) except the total coliform and *E. coli*. The raw sewage of WSPs had BOD concentrations of 204 mg/l and therefore it can be classified as weak. The quality of the final effluents of the WSPs also had BOD concentrations of less than 50.0 mg/l which fell within the acceptable EPA guideline value and will not have any adverse effect on the Onyease stream into which it is discharged.

A high coliform reduction of 99.9 % was achieved; however, it could not meet the EPA recommended *E. coli* value of 10 cfu/100ml, thereby making it unacceptable. From the results, it can be deduced that the treatment plant located at Legon campus is functioning well with respect to BOD, COD and TSS reduction as shown by the percentage removal. The treatment efficiency for the nutrient level in the wastewater was better in Legon sewage treatment plant WSP which recorded removal percentages of 85.2 and 58.7% for ammonia nitrogen and phosphate phosphorus respectively. The reductions were very high in all cases indicating higher removal. However, the *E. coli* reduction from the Legon sewage treatment plant did not meet the EPA quality requirement for effluent discharged into the environment despite a 99.9 percent removal efficiency. At $p \leq 0.05$, there was a significant difference between the influent the effluent.

Similarly the heavy metals concentrations from the sludge from the various ponds (ie) anearobic, facultavie, maturation-1 and matruation-2 ponds from both stream-1 and 2 were within the acceptable limits for metals brought to agriculture land by sewage sludge in South Africa (SFS, 1998:944; Water Research Commission, 1997). At $p \geq 0.05$, there was no significant difference between the stream one and stream two ponds in terms of sludge quality. Sludge from Legon wastewater treatment plant, can be used as a soil conditioner, in the form of organic compost manure for supplying the crop with nitrogen, phosphorus and potassium. Sludge can be a stable source of organic matter which improves the organic matter content in soils.

5.2 Recommendations

The following are recommended base on the findings of the studies:

- Since the *E. coli* load discharged into the Onyease stream as the final effluent quality was higher than EPA recommended value, it is recommended that further treatment by chlorination should be applied to meet the environmental quality standard.
- Further studies on the treatment plant should be carried out to determine the rate of sludge accumulation (kg/year) in all the ponds.
- Determination of the dewaterability of the different pond sludges
- There should be a periodic water quality monitoring on the Onyease stream in order to determine the effect of the WSP final effluent on the stream, since the stream is a source of water used for vegetable irrigation.

- Further studies on the sewage sludge including other heavy metals like mercury, indicator microorganisms and pathogen levels in sludge should be done before a decision is made on the use of the sewage sludge as a soil improver.
- Studies should be conducted on the suitability of the organic compost (manure) produced by the pond sludge for agriculture use.

REFERENCES

Abis, K., & Mara, D.D. (2003). Research on Waste Stabilization Ponds in the United Kingdom. Initial Results from Pilot-scale Facultative Ponds. *Water Science and Technology*, 48, 1–8.

Alloway, B. J. (1995a). *Heavy metals in soils*. Blackie: New York.

Akrivos, J., Mamais, D., Katsara, K., & Andreadakis, A. (2000). Agricultural utilization of lime treated sewage sludge. *Water Science and Technology*, 42, 203-210.

American Public Health Association (APHA) (2012). *Standard Methods for the Examination of Water and Wastewater*. New York: USA.

Apal Agricultural Laboratory (2019). Soil Test Interpretation Guide.

Arceivala, S. J. (1981). Wastewater Treatment and Disposal, Pollution Engineering and Technology. Inc., New York, Marcel Dekker.

Australian Bureau of Statistics (ABS) (2012). *Australian Demographic Statistics,* Australian Bureau of Statistics. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0>.

Bright and Healey. (2003). Contaminant risk from biosolids land application, British Columbia. *Journal of environmental pollution*, 126(1), 39-49.

Brennan and Bell (2013) Soil K-crop response calibration relationships. *Crop and Pasture Science,* 64, 514-522.

Bresters, A.R., Columb, I., Deak, B., Matter, B., Saabye, A., Spinosa, L., Utvik, A.O., (1997). *Sludge Treatment and Disposal*. Copenhagen: European Environment Agency.

Brewer, G.J. (2007). Iron and copper toxicity in diseases of the aging, particularly artherosclerosis and Alzheimers disease. *Experimental and Biological Medicine (Maywood)* 232(2), 323–35.

Chapman, D. (1996). *Water Quality Assessment*. EPFN Spon: London.

Cheryl & Susan. (2000). Reflections on hexavalent chromium. *Environmental Health Perspective*, 9, 108-109.

Clescerl, L. S., Greenberg, A. E., & Eaton, A. D. (2008). *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association: Washington, DC.

Coggins, L.X (2011). *Impact of sludge accumulation on the hydraulic efficiency of waste stabilisation ponds: Towards sustainable management of wastewater sludge in Australia.* Hons. Thesis: The University of Western Australia.

Counter, S., Buchaman, L. & Ortega, F. (1998). Blood mercury and auditory neurosensory responses in children and adults in the Nambija and Mining area of Ecuador. *Neurotoxicity*, 19, 185-196.

Craggs, R. J., Green, F. B. and Oswald, W. J. (1999). Economic and energy requirements of advanced integrated wastewater pond systems (AIWPS). In *Proceedings of the NZWWA Annual Conference*, 1−7.

Curtis, T. P., Mara, D. D., & Silva, S. A. (1992). Influence of pH, oxygen & humic substances on ability of sunlight to damage faecal coliforms in waste stabilization pondwater. *Applied and Environmental Microbiology,* 58(4), 1335−1345.

DeGarie, C. J., Crapper, T., Howe, B. M., Burke B. F. & McCarthy, P. J. (2000). Floating geomembrane covers for odour control and biogas collection and utilization in municipal lagoons. *Water Science and Technology,* 42(10−11), 291−298.

Dennis, P., Brent F., Fionna, M. & Brent, K. (2003). Human Health Risk and Exposure Assessment of Chromium (VI) in Tap Water. *Toxicol and health*, 66, 1295-1339.

Ofori-Amanfo, D., Rockson, G.N.K., Arthur, A., & Ahmed, I. (2018). Processing dewatered faecal sludge into unpelletized fertilizer for crop production in greater Accra-Ghana. *International Journal of Environmental Monitoring and Analysis*, 6(1), 18–25.

Domestic Wastewater Treatment in Developing Countries (2004). London: Earthscan Publications.

Drinan & Whiting, (2001). *Water & Wastewater Treatment: A Guide for the Nonengineering Professional*. Technomic Pub Co.

Emongor, V. E. & Ramolemana, G. M. (2004). Treated sewage effluent (water) potential to be used for horticulture production in Botswana. *Physics and Chemistry of the Earth,* 29, 1101-1108.

Environmental Protection Agency (1999). *Biosolids Generation, Use and Disposal in the United States.* EPA 530-R-99-009.

EU (2000). *Working Document on Sludge 3rd Draft.* Unpublished, 19 p.

Faller, P. (2009). Copper and zinc binding to amyloid-beta: coordination, dynamics, aggregation, reactivity and metal-ion transfer. *Chembiochem,* 10(18), 2837–45.

Ghazy, M. M., El-Senousy, E. W. M., Abdel-Aatty, A. M., & Mohammed, K. (2008). Performance Evaluation of a Waste Stabilization Pond in a Rural Area in Egypt. *American Journal of Environmental Sciences* 4(4), 316-325.

Motsara & Roy (2008). Guide to laboratory establishment for plant nutrient analysis.

Hammer, M. & Hammer, M. (2014). *Water and Wastewater Technology*. Harlow: Pearson Education Limited.

Pearson, H.W., Mara, D.D., & Arridge, H.A. (1995). The influence of pond geometry and configuration on facultative and maturation waste stabilisation pond performance and efficiency. *Water Science and Technology,* 31(12), 129-139.

Health guidelines for the use of wastewater in agriculture and aquaculture (1989). *Report of WHO Scientific Group.*

Henze, M. (1996). Biological phosphorus removal from wastewater: processes and technology. *Water Quality International*, 32-36.

Hodgson, I. O. A. & Larmie, S. A. (1998**).** *An evaluation of the treatment efficiencies of the sewage treatment ponds at Akosombo.* CSIR-WRI, Technical Report.

Hodgson, I. O. A. (2000). Treatment of Domestic Sewage at Akuse (Ghana), *Water SA*, 26(3), 413-415.

Hodgson, I. O. A. (2003). Diurnal Variation of quality of Sewage and Effluent in Waste Stabilization and Treatment Ponds at Akosombo. *JAST,* 8(1&2), 5-6.

Hodgson O. A. Isaac, (2007). Performance of the Akosombo Waste Stabilization Ponds in Ghana. *Ghana J. Sci.* **47** (2007), 35-44

Howard, P., & Yosi, A. (2000). *Waste Stabilization Ponds: Technology and the Environment (Proceedings of the Fourth IAWQ International Specialist Conference on WSP*. IWA Publishing: London.

Jagadish, P.P. (2010). *Conceptual Pharmacology*. Universities Press.

Jensen, J. & Jepsen, S. E. (2005). The production, use and quality of sewage sludge in Denmark. *Waste Management,* 25(3), 239-47.

Karvelas, M., Athanasios, K., & Samara, C. (2003). Occurrence and fate of heavy metals in the

wastewater treatment process. *Chemosphere*, 53(10), 1201–1210.

Kesse, G.O. (1985) *The Mineral and Rock Resources of Ghana, AA Balkema.* Rotterdam. The Netherlands.

Korentajer, L., 1991. A review of the agricultural use of sewage sludge: Benefits and potential hazards. *Water SA, Volym,* 17(3), 189-196.

Levlin, E., Tidestrom, H., Kapilashrami, S., Stark, K., & Hultman, B. (2001). *Slamkvalitet och trender for slamhantering,* Stockholm:VAV AB.

Mara, D. D., & Oragui, J.I. (1981). Occurrence of Rhodococcus coprophilus and associated actinomycetes in faeces, sewage and freshwater. Applied and Environmental Microbiology 42(6), 1037−1042.

Mara, D.D., & Pearson, H.W. (1992). Sequential Batch-fed Effluent Storage Reservoirs: A new concept of wastewater treatment prior to unrestricted crop irrigation. *Water Science and Technology*, 26(7–8), 459–1464.

Mara, D.D. (2004). *Domestic Wastewater Treatment in Developing Countries*. London: Earthscan Publications.

Metcalf and Eddy Inc. (1985). *Wastewater Engineering: Treatment, Disposal and Reuse.* McGraw-Hill: New York.

Moody, P.W. (2007) Interpretation of a single-point P buffering index for adjusting critical levels of the Colwell soil P test. *Australian Journal of Soil Research,* 45, 55-62.

Morgan, D. (2010). *Application of Sonar for the Measurement of Sludge Heights in Wastewater Stabilisation Ponds.* Hons. Thesis: The University of Western Australia.

Morrison G., Fatoki, O., Linder, S., & Lundehn, C. (2004). *Determination of heavy metal concentrations and metal fingerprints of sewage sludge.* Eastern Cape Province.

Mulder J.W., & Rensink, J.H. (1987**)**. *Introduction of biological phosphorus removal to an activated sludge plant with practical limitations, Biological Phosphate Removal from Wastewaters. In Advances in Water Pollution Control.* Pergamon: England.

Naturvårdsverket, (2008). *Rening av avloppsvatten i Sverige*: Naturvårdsverket

Nelson, K.L., Cisneros, B.J., Tchobanoglous, G., & Darby, J.L. (2004). Sludge accumulation, characteristics, and pathogen inactivation in four primary waste stabilization ponds in central Mexico. *Water Research*, 38(1), 111-127.

Nester, E.W., Anderson, D.G., Nester, M.T., Pearsall, N.N., Roberts, C.E., & Hurley, D. (2004). Microbiology: A Human Perspective, 4th edition, McGraw- Hill: University of Washington.

Ngole, V., Otlogetswe, T., & Mpuchane, S. (2006). The effect of ageing on the fertilizer

value of

sludge from Botswana. *J.Appl.Sci.Environ., Volym,* 10(3), 109-115.

Okoh, A. E. (2010). *Water Auditing of a Ghanaian Beverage plant,* 115

Oliver, M. A. (2011). *Soil and Human Health. Department of Soil Science,* The University of Reading: Whiteknights.

Oliver, B. G., & Cosgrove, E. G., (1974). The efficiency of heavy metal removal by a conventional activated sludge treatment plant. *Water Research,* 8, 869-874.

Peña, M.R., & Gijzen, H.J. (2002). *Waste Stabilization Ponds in Latin America (Proceedings of the First Latin American Regional Conference on WSP)*. IWA Publishing: London.

Peña Varón, M.R., Rodrigues, J., Mara, D.D., & Spulveda, M. (2000). UASBs or Anaerobic Ponds in Warm Climates? A preliminary answer from Colombia', Water Science and Technology, 42(10), 59–65.

Picot, B., Sambuco, J.P., Brouillet, J.L., & Riviere, Y. (2005). Wastewater stabilisation ponds: sludge accumulation, technical and financial study on desludging and sludge disposal case studies in France, *Water Science and Technology,* 51(12), 227-234.

Samadi-Maybodi, R.V. (2014). *Sensors and Actuators B: Chemical.* Elsevier

Sanin, F. D., Clarkson, W. W., & Vesilind, P. A. (2011). *Sludge Engineering: The Treatment and Disposal of Wastewater Sludges.* Pennsylvania: DEStech Publications, Inc.

Sedlak, R. (1991). *Phosphorus and nitrogen removal from municipal wastewater: Principles and practice.* Lewis publishers, USA.

Shilton, A. (2005). *Pond Treatment Technology.* IWA Publishing: London.

Shuval, H., Lampert, Y., & Fattal, B. (1997). Development of a Risk Assessment Approach for Evaluating Wastewater Reuse Standards for Agriculture, *Water Science and Technology*, 35(11)–12, 15–20.

Snyman, H., & Van der Waals, J. (2004*). Laboratory and field scale evaluation of agriculture use of sewage sludge.* Department of Plant Production and Soil Science: University of Pretoria.

Snyman, H., Terblanche, J. & Van der Westhuizen, J. (2000). Management of Land Disposal and Agricultural Reuse of Sewage Sludge within the framework of the current South African guidelines. *Water science and technology,* 42(9), 13-20.

Sommers, L. E., 1977. Chemical composition of sewage sludge and analysis of their potential use as fertilizer. *Journal of Environmental Quality*, 6(2), 225-232.

Suresh Kumar Rohilla, Bhitush Luthra, Shantanu Kumar Padhi and Anil Yadav 2019, *Integrated Wastewater and Faecal Sludge Management for Ghana: Draft Guidelines*, Centre for Science and Environment, New Delhi

Stoeppler, M., & Backhaus, F. (1978) Pre-treatment with Biological and Environmental Samples’, *Fresentius Z. Anal. Chem*, 291, 116-120. Tandon, H. S. L. (1994). *Fertilizers Organic Manures, Recyclable Wastes and biofertilizers.*

FDCO: New Delhi.

Tervahautaa, T., Rania, S., Hernandez Leala, L., Buismana, C. J.N., & Zeemanba, G. (2014). Black water sludge reuse in agriculture: Are heavy metals a problem? *Journal of Hazardous Materials*, 274, 229-236.

Tchobanoglous, G., Burton, F., & Stensel, H. D. (2003). *Wastewater Engineering: Treatment, Disposal and Reuse.* McGraw Hill Publishing Company.

United Nations Environmental Programme (1984a). Determination of Total Cadmium, Zinc, Lead and Copper in Selected Marine Organisms by Flameless Atomic Absorption Spectrophotometry. *Reference Methods for Marine Pollution Studies,* 11, 1.

United Nations Environmental Programme (1984b). Sampling of Selected Marine Organisms and Sample Preparation for Trace Metal Analysis. *Reference Methods for Marine Pollution Studies*, **7**, 2.

University of Ghana (2019). Enrolment and graduation statistics. Retrieved from http://www.ug.edu.gh/about/enrolment-and-graduation-statistics

Uz, G., Turak, F., & Afsar, H. (2004). Research of BOD and COD values of wastewaters that contain certain organic materials. Adnan Menderes University, 4th AACD Congress, *Turkey Proceedings Book,* 177.

Wang, J., Huang, C.P., Herber, E.A., Poesponegoro, I., Poesponegoro, H., & Takiyama, L.R.

(1999). Effects of dissolved organic matter ad pH on heavy metal uptake by sludge particulates exemplified by copper and nickel: three-variable model. *Water Environ. Research*, 71, 139-147.

Water Research Commission (1997). *Permissible Utilisation and Disposal of Sewage Sludge* Water Research Commission: Pretoria.

Wenzel, M.C., & Ekama, G.A. (1997). *Principles in the design of single sludge activated sludge*

systems for biological removal of carbon, nitrogen and phosphorus. In La dephosphatation des eaux usees. CEBEDOC: Belgium.

World Health Organisation (1989). Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture.

Report of a Scientific Group. *World Health Organisation Technical Report Series,* 778.

World Health Organization. (2004). *Guidelines for Drinking Water Quality*. *International programme on chemical safety*. Geneva.

World Health Organisation (2011). Cadmium in drinking-water. Background document for development of WHO guidelines for drinking water quality. World Health Organization, Geneva.

Retrieved from www.who.int/water_sanitation_health/dwq/chemicals/cadmium.pd

APPENDICES

APPENDIX A: EFFLUENT QUALITY ANALYSIS

SAMPLE ID	**pH**	**Cond**	**Col.**	**Turb**	**TDS**	**TSS**	**Ca**	**Mag.**	**Cl**	**Tot. H**	**Tot.Alk**	**HCO3**
UNITS	**pH Units**	**µS/cm**	**Hz**	**NTU**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
RAW-OCT	7.24	847	250	427	508	439	28.9	6.80	99.3	109	368	449
RAW-OCT	7.20	840	255	422	502	436	28.1	6.76	98.7	105	365	445
RAW-OCT	7.22	844	255	425	506	435	28.6	6.83	98.5	103	366	447
AVE	7.22	844			**505**	**437**			**98.8**	**106**	**366**	
STDEV	**0.016**	**2.48**			**2.49**	**1.70**			**0.340**	**2.494**	**1.247**	
RAW-NOV	7.48	1220	150	485	732	509	22.4	5.80	95.3	80	416	508
RAW-NOV	7.26	1225	150	485	736	505	22.9	5.50	93.3	79	410	500
RAW-NOV	7.29	1220	158	480	732	502	22.6	5.60	96.1	82	412	503

AVE	**7.34**	**1222**			**733**	**505**			**94.9**			
STDEV	**0.084**	**2.04**			**1.63**	**2.48**			**1.02**			
RAW-DEC	7.34	968	175	420	581	470	22.4	13.60	101.0	127	376	459
RAW-DEC	7.20	974	179	420	581	470	23.1	11.20	98.6	119	378	461
RAW-DEC	7.18	977	172	428	586	475	22.9	12.40	99.2	122	375	458
AVE	**7.24**	**973**			**583**	**472**			**99.6**			
STDEV	**0.1**	**3**			**2.04**	**2**			**0.9**			
RAW-JAN	7.02	833	110	296	500	242	20.8	7.80	115.0	84	392	478
RAW-JAN	7.08	838	114	302	505	248	21.4	7.40	118.0	87	385	470
RAW-JAN	7.11	841	115	300	508	245	21.6	7.10	120.0	85	389	475
AVE	**7.07**	**837**		**299**	**3.30**	**245**			**117.7**			
STDEV	**0.032**	**2.86**		**2.16**	**217**	**2.12**			**1.78**			
	7.57	1614	188	611	968	592	19.2	9.72	105.0	88	516	630

RAW-FEB	7.44	1620	185	615	974	598	19.5	9.50	100.0	86	512	625
RAW-FEB	7.40	1618	184	618	979	594	19.8	9.86	103.0	85	510	622
AVE	**7.47**	**1617**			**974**	**595**						
STDEV	**0.063**	**2.16**			**3.89**	**2.16**						
RAW-MAR	7.20	1013	50	160	557	194	13.6	3.60	76.4	49.0	221	270
RAW-MAR	7.29	1015	56	166	552	191	14.2	3.80	78.4	51.0	224	273
RAW-MAR	7.31	1016	53	162	555	196	13.9	3.60	77.5	48.5	225	275
AVE	**7.27**	**1015**			**555**	**194**						
STDEV	**0.041**	**1.08**			**1.83**	**1.78**						
FINAL-OCT	8.83	511	38	104	307	74.0	16.0	3.89	97.7	56	159	194
FINAL	8.83	511	35	100	309	70.0	16.3	3.80	97.2	55	160	195
FINAL	8.86	513	36	102	306	72.0	16.5	3.86	97.5	56	158	193

AVE	**8.84**	**512**			**307**	**72.0**			**97.5**			
STDEV	**0.012**	**0.816**			**1.08**	**1.4**			**0.178**			
FINAL-NOV	7.54	556	25.0	74.0	334	66.0	56.0	11.2	94.7	56.0	127	155
FINAL	7.61	560	28.0	75.3	337	66.9	57.2	10.6	95.1	56.2	127	155
FINAL	7.68	564	26.0	73.8	335	65.8	55.8	10.9	94.9	55.8	126	154
AVE	**7.61**	**560**			**335**	**66.2**			**94.9**			
STDEV	**0.049**	**2.83**			**1.08**	**0.414**			**0.141**			
FINAL-DEC	8.54	621	35.0	68.0	373	54.0	16.0	5.80	81.8	64.0	118	144
FINAL	8.78	625	36.4	69.4	384	54.9	16.9	5.50	81.0	64.4	120	146
FINAL	8.69	629	35.8	68.0	379	54.6	16.0	5.70	81.4	64.2	118	144
AVE	**8.67**	**625**			**379**	**54.5**			**81.4**			
STDEV	**0.086**	**2.83**			**3.89**	**0.324**			**0.283**			

FINAL-JAN	8.74	637	100	96.0	382	86.0	17.6	6.80	91.3	72.0	124	151.3
FINAL	8.86	641	102	98.6	390	87.6	16.8	7.40	92.6	72.5	126	154
FINAL	8.92	644	105	95.4	386	85.8	17.2	7.10	92.0	71.8	127	155
AVE	**8.84**	**641**			**386**	**86.5**			**92.0**			
STDEV	**0.065**	**2.48**			**2.83**	**0.698**			**0.460**			
FINAL-FEB	9.46	674	37.5	81.0	404	80.0	12.8	9.72	101	72.0	146	178
FINAL	9.31	680	40.0	85.0	412	86.0	11.6	9.85	105	72.5	144	176
FINAL	9.38	685	37.5	82.5	400	82.0	11.2	9.93	108	71.8	140	171
AVE	**9.38**	**680**			**405**	**82.7**			**105**			
STDEV	**0.053**	**3.89**			**4.32**	**2.16**			**2.48**			
FINAL-MAR	7.59	659	10.0	91.0	362	60.0	22.0	1.70	107.20	62.0	115	141
FINAL	8.66	660	15.0	18.0	365	58.0	24.0	1.90	107.00	63.0	116	141
FINAL	8.70	664	12.0	20.0	368	62.0	21.8	1.80	105.00	60.0	118	142

AVE	**8.32**	**661**			**365**	**60.0**			**106.40**			
STDEV	**0.445**	**1.87**			**1.96**	**1.41**			**0.860**			
EPA VALUE	**6.0-9.0**	**1500**			**1000**	**50.0**						

SAMPLE ID	**NH_3-N**	**NO_2-N**	**NO_3-N**	**PO4-P**	**SO4**	**Pot.**	**Na**	**COD**	**BOD**	**SAR**	**TC**	**FC**	**E.Coli**
UNITS	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**meq/l**	**cfu/100ml**	**cfu/100ml**	**cfu/100ml**
RAW - OCT	15.3	0.249	0.15	3.51	65.8	28.30	79.3	864	180	3.45	290X106	180X106	160X106
RAW - OCT	14.8	0.046	0.14	3.46	63.8	28.60	78.4	870	184	3.45			
RAW - OCT	15.0	0.043	0.14	3.49	61.8	28.10	79.0	863	186	3.45			
AVE	**15.0**		**0.14**	**3.49**	**63.8**			**866**	**183**	**3.45**			
STDEV	**0.178**		**0.002**	**0.021**	**1.6**			**3.09**	**2.16**	**0.001**			
RAW - NOV	13.6	0.311	0.31	5.66	66.9	25.90	76.9	1280	239	3.75	23X107	13X107	12X107

RAW-NOV	12.8	0.018	0.31	5.55	65.5	24.70	74.2	1283	242	3.61			
RAW-NOV	13.0	0.015	0.31	5.48	67.3	25.10	75.7	1287	236	3.70			
AVE	**13.1**		**0.31**	**5.56**				**1283**	**239**	**3.685**			
STDEV	**0.294**		**0.002**	**0.064**				**2.48**	**2.12**	**0.047**			
RAW-DEC	13.9	0.183	0.16	3.18	75.1	26.80	79.6	880	105	3.275	37X107	10X107	9X107
RAW-DEC	12.6	0.191	0.17	3.96	76.8	27.40	78.2	880	109	3.341			
RAW-DEC	13.1	0.188	0.17	4.06	74.5	26.60	78.5	876	105	3.284			
AVE	**13.2**		**0.17**	**3.73**				**879**	**106**	**3.300**			
STDEV	**0.5**		**0.00**	**0.34**				**2**	**2**	**0.025**			
RAW-JAN	15.2	0.208	0.16	3.74	72.8	26.90	86.1	480	114	4.087	14X107	10X107	10X107
RAW-JAN	15.8	0.196	0.15	3.68	72.0	26.50	86.3	489	108	4.100			
RAW-JAN	15.6	0.203	0.16	3.65	71.9	26.10	86.7	483	102	4.138			

AVE	**15.5**		**0.16**	**3.69**				**484**	**108**	**4.108**			
STD EV	**0.216**		**0.003**	**0.032**				**3.24**	**4.24**	**0.019**			
	11.9	0.241	1.13	3.16	69.4	34.00	88.5	422	241	4.107	22X107	8X107	8X107
RAW-FEB	11.2	0.229	1.19	5.25	68.2	36.20	86.9	428	236	4.036			
RAW-FEB	10.8	0.236	1.16	5.24	68.0	35.90	88.2	435	230	4.045			
AVE	**11.3**		**1.16**	**4.55**				**428**	**236**	**4.063**			
STD EV	**0.394**		**0.021**	**0.853**				**4.60**	**3.89**	**0.027**			
RAW-MAR	12.7	0.046	0.32	3.56	63.0	26.80	78.0	976	348	4.212	532X107	260X107	240x107
RAW-MAR	11.9	0.052	0.36	3.60	68.0	25.90	75.8	985	355	4.615			
RAW-MAR	12.3	0.050	0.35	3.39	65.8	28.60	76.9	981	352	4.755			
AVE	**12.3**		**0.344**	**3.52**				**981**	**352**	**4.527**			

STDEV	**0.283**		**0.013**	**0.078**				**3.19**	**2.48**	**0.199**			
FINAL-OCT	2.55	0.086	0.19	1.95	22.6	33.10	85.1	136	39.8	4.951	56X103	3X103	2.6X103
FINAL	2.60	0.086	0.19	1.98	23.2	33.40	84.8	138	33.2	4.916			
FINAL	2.50	0.080	0.20	1.96	22.9	33.50	85.0	134	37.6	4.896			
AVE	**2.55**		**0.194**	**1.96**				**136**	**36.9**	**4.921**			
STDEV	**0.035**		**0.002**	**0.011**				**1.41**		**0.020**			
FINAL-NOV	3.49	0.073	0.51	1.85	21.4	31.60	81.6	130	23.6	2.604	372X102	1X103	1X103
FINAL	3.41	0.078	0.51	1.78	21.8	32.10	82.4	134	24.8	2.626			
FINAL	3.45	0.070	0.50	1.81	21.5	31.80	81.9	137	25.2	2.626			
AVE	**3.45**		**0.506**	**1.81**				**134**	**24.5**	**2.619**			
STDEV	**0.028**		**0.004**	**0.025**				**2.48**	**0.589**	**0.009**			

FINAL-DEC	1.63	0.044	0.19	2.34	28.30	30.80	89.5	138	27.0	4.875	24X105	10X105	9X105
FINAL	1.63	0.052	0.19	2.34	27.30	29.80	88.3	141	29.3	4.772			
FINAL	1.65	0.048	0.21	2.38	27.10	30.10	87.9	140	28.6	4.804			
AVE	**1.64**		**0.20**	**2.35**				**140**	**28.3**	**4.82**			
STDEV	**0.008**		**0.009**	**0.016**				**1.08**	**1.67**	**0.037**			
FINAL-JAN	1.19	0.113	0.05	1.06	26.90	32.80	91.80	147	28.3	4.710	279X102	1X102	1X102
FINAL	1.26	0.118	0.08	1.13	27.30	31.60	88.90	149	26.5	4.547			
FINAL	1.23	0.115	0.06	1.15	27.00	31.90	89.60	151	27.8	4.590			
AVE	**1.23**		**0.07**	**1.11**				**149**	**27.5**	**4.62**			
STDEV	**0.025**		**0.011**	**0.033**				**1.41**	**0.657**	**0.060**			
FINAL-FEB	1.597	0.136	0.46	1.44	29.40	25.8	83.5	115	17.2	4.283	93X103	1X102	1X102

FINAL	1.605	0.145	0.51	1,58	29.00	26.9	85.8	121	18.3	4.479			
FINAL	1.595	0.142	0.52	1.55	28.80	26.5	83.9	118	18.9	4.401			
AVE	**1.599**		**0.496**	**1.55**				**118**	**18.1**	**4.39**			
STD EV	**0.004**		**0.024**	**0.000**				**2.12**	**0.610**	**0.070**			
FINAL-MAR	1.395	0.025	0.128	1.760	25.14	30.60	95.0	128	25.4	5.25	18X102	0	0
FINAL	1.405	0.030	0.135	1.180	28.60	31.80	92.50	133	26.3	4.89			
FINAL	1.408	0.028	0.130	1.200	26.50	32.50	90.60	138	26.9	5.01			
AVE	**1.403**		**0.131**	**1.38**				**133**	**26.2**	**5.05**			
STD EV	**0.005**		**0.003**	**0.233**				**3.54**	**0.534**	**0.130**			
EPA VALUE	**1.00**		**50.0**	**2.0**				**250**	**50.0**				

SAMPLE ID	**Zn**	**Cu**	**Pb**	**Fe**	**Mn**	**Cr**
UNITS	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**

FINAL-OCT	0.172	0.172	0.011	1.34	0.429	0.019
FINAL-OCT	0.19	0.185	0.020	1.25	0.415	0.017
FINAL-OCT	0.179	0.121	0.013	1.23	0.668	0.012
AVE	**0.211**	**0.1593**	**0.015**	**1.273**	**0.504**	**0.016**
STDEV	**0.017**	**0.0276**	**0.004**	**0.046**	**0.116**	**0.003**
FINAL-NOV	0.204	0.155	0.008	1.720	0.461	0.016
FINAL-NOV	0.183	0.175	0.014	1.810	0.449	0.022
FINAL-NOV	0.188	0.163	0.017	1.930	0.601	0.019
AVE	**0.203**	**0.1643**	**0.013**	**1.820**	**0.504**	**0.019**
STDEV	**0.011**	**0.0082**	**0.004**	**0.086**	**0.069**	**0.002**
FINAL-DEC	0.213	0.168	0.019	1.740	0.521	0.024
FINAL-DEC	0.219	0.159	0.016	1.590	0.518	0.021
FINAL-DEC	0.186	0.144	0.019	1.820	0.533	0.016
AVE	**0.226**	**0.157**	**0.018**	**1.717**	**0.524**	**0.020**
STDEV	**0.017**	**0.0099**	**0.001**	**0.095**	**0.006**	**0.003**
FINAL-JAN	0.182	0.115	0.009	1.480	0.395	0.023
FINAL-JAN	0.169	0.138	0.018	1.390	0.421	0.021

FINAL-JAN	0.155	0.131	0.016	1.410	0.481	0.018
AVE	**0.247**	**0.128**	**0.014**	**1.427**	**0.432**	**0.021**
STDEV	**0.041**	**0.0096**	**0.004**	**0.039**	**0.036**	**0.002**
FINAL-FEB	0.191	0.108	0.017	1.530	0.451	0.016
FINAL-FEB	0.172	0.118	0.024	1.320	0.438	0.022
FINAL-FEB	0.189	0.101	0.015	1.290	0.536	0.018
AVE	**0.221**	**0.109**	**0.019**	**1.380**	**0.475**	**0.019**
STDEV	**0.02**	**0.007**	**0.004**	**0.107**	**0.043**	**0.002**
FINAL-MAR	0.154	0.125	0.018	1.47	0.461	0.021
FINAL-MAR	0.161	0.149	0.012	1.58	0.439	0.014
FINALMAR	0.146	0.136	0.016	1.32	0.568	0.016
AVE	**0.205**	**0.1367**	**0.015**	**1.457**	**0.489**	**0.017**
STDEV	**0.026**	**0.0098**	**0.002**	**0.107**	**0.056**	**0.003**
EPA VALUE						

APPENDIX B: Sludge Quality Chemical Analysis

Discription	**Depth**	**pH(H$_2$0)**	**Elect.**	**Moist**	**Nitrogen**	**OC**	**OM**
	(cm)	**(1:2.5)**	**Condt**	**%**	**mg/kg**	**%**	**%**
			µS/cm				
AS1		6.9	1147	96.3	16900.00	19.6	33.7
AS1		7.0	1126	97.1	19000.00	22.1	38.0
AS1		6.9	1180	95.3	18600.00	21.6	37.2
AS1		6.5	1249	97.2	17100.00	19.9	34.2
AS1		6.9	1280	95.9	16800.00	19.5	33.5
AS1		6.8	1184	96.9	18300.00	21.3	36.6
AVE		**6.8**	**1194**	**96.45**	**17783.33**	**20.7**	**35.5**
STDEV		**0.1**	**50.1**	**0.636**	**813.136**	**0.957**	**1.7**
AS2		6.0	1395	96.2	15000.00	17.4	29.9
AS2		6.8	1369	97.4	17900.00	20.9	35.9
AS2		6.6	1310	95.1	17500.00	20.3	34.9
AS2		6.7	1275	96.8	17700.00	20.6	35.4
AS2		6.9	1269	96.5	17100.00	19.9	34.2
AS2		6.9	1240	96.4	19000.00	22.1	38.0
AVE		**6.6**	**1309.667**	**96.4**	**17366.67**	**20.2**	**34.7**

STDEV		**0.3**	**55.54478**	**0.64365**	**1118.247**	**1.320173**	**2.3**
FS1		6.6	1416	98.0	13200.00	13.0	22.4
FS1		6.5	1454	96.6	14500.00	16.8	28.9
FS1		7.5	1420	98.0	13250.00	15.4	26.5
FS1		7.8	1455	97.4	12200.00	14.1	24.3
FS1		7.6	1470	97.8	12400.00	14.4	24.8
FS1		7.7	1415	97.8	12500.00	14.5	24.9
AVE		**7.3**	**1438.333**	**97.6**	**13008.33**	**14.7**	**25.3**
STDEV		**0.5**	**20.37272**	**0.5**	**717.345**	**1.1**	**1.9**
FS2		6.1	1765	93.8	13300.00	8.49	14.6
FS2		6.3	1580	95.9	12600.00	14.6	25.1
FS2		7.1	1530	97.9	12800.00	14.9	25.6
FS2		7.5	1518	97.1	11950.00	13.9	23.9
FS2		7.9	1546	97.4	12200.00	14.2	24.4
FS2		7.4	1508	97.6	12200.00	14.2	24.4
AVE		**7.1**	1574.5	96.61667	**12508.33**	**13.38167**	**23**
STDEV		0.6	81.70286	1.304297	**417.832**	**2.046812**	**3.51446**
MS1-1		6.6	1422	97.8	6940.00	4.58	7.88

MS1-1		6.8	1460	97.1	7150.00	8.31	14.3
MS1-1		7.8	1490	97.6	6450.00	7.49	12.88
MS1-1		8.1	1475	97	6100.00	7.10	12.2
MS1-1		7.8	1520	97.6	6450.00	7.52	12.9
MS1-1		7.8	1452	97.4	6800.00	7.90	13.58
AVE		**7.5**	**1469.833**	**97.41667**	**6648.333**	**7.15**	**12.29**
STDEV		**0.5**	**28.41738**	**0.264125**	**324.936**	**1.12**	**1.922818**
MS1-2		6.8	1716	94.9	5715.00	4.32	7.43
MS1-2		6.9	1652	95.8	5550.00	6.44	11.1
MS1-2		7.3	1620	97.8	5900.00	6.88	11.8
MS1-2		7.6	1596	97.2	6600.00	7.70	13.2
MS1-2		7.6	1565	97.4	6350.00	7.39	12.7
MS1-2		7.5	1569	97.5	6350.00	7.40	12.7
AVE		**7.3**	**1619.667**	**96.76667**	**6077.500**	**6.69**	**11.49393**
STDEV		**0.3**	**48.46403**	**0.971989**	**351.057**	**1.050828**	**1.79706**
MS2-1		7.0	2670	83.8	3500.00	3.51	6.04
MS2-1		6.8	2430	94.6	4135.00	4.81	8.27
MS2-1		7.5	2465	95.5	4480.00	5.21	8.96
MS2-1		7.9	2448	96.8	4610.00	5.36	9.22
MS2-1		7.7	2390	97.3	4250.00	4.94	8.50

MS2-1		7.7	2389	97.7	4385.00	5.10	8.77
AVE		**7.4**	**2465.333**	**94.28333**	**4226.667**	**4.821667**	**8.2928**
STDEV		**0.4**	**88.59163**	**4.449532**	**332.347**	**0.567285**	**0.974666**
MS2-2		6.8	2360	87.8	3160.00	3.68	6.32
MS2-2		6.9	2389	93.8	5100.00	5.93	10.2
MS2-2		7.7	2436	96.3	4960.00	5.77	9.92
MS2-2		7.8	2469	96.5	4805.00	5.59	9.61
MS2-2		7.8	2435	97.6	4525.00	5.26	9.05
MS2-2		7.9	2430	97.5	4430.00	4.86	8.86
AVE		**7.5**	**2419.833**	**94.91667**	**4496.667**	**5.181667**	**8.9935**
STDEV		**0.4**	**32.82602**	**3.166529**	**593.499**	**0.700763**	**1.187348**

Sludge Quality Chemical Analysis

Discrip tion	**Total.**	**Avail .**	**Total.**	**Avail.**	**Exchangeable Cation (Cmol(+)/ kg)**			

	Phos	Phos	Potas	Potas				
	(mg/kg)	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**K**	**Na**	**Ca**	**Mg**
AS1	380.4348	10.7	210	8.4	0.240	0.505	41.3	7.08
AS1	358.6957	10.1	212	8.1	0.289	0.529	42.5	7.83
AS1	408.6957	9.4	208	8	0.241	0.539	43.6	6.33
AS1	393.4783	9.3	210	8.9	0.262	0.591	37.5	5.92
AS1	347.8261	9.8	206	8.6	0.292	0.522	40.5	6.67
AS1	404.3478	9.2	209	8.1	0.262	0.548	41.0	6.67
AVE	**382.2464**	**9.8**	**209**	**8.35**	**0.264**	**0.539**	**41.1**	**6.75**
STDEV	**20.89726**	**0.5**	**1.7**	**0.296**	**0.019**	**0.025**	**1.8**	**0.56**
AS2	384.7826	10.4	202	8.6	0.164	0.487	34.4	6.72

AS2	332.6087	9.4	205	8.88	0.197	0.463	43.2	7.37
AS2	369.5652	9.1	200	8.3	0.210	0.557	42.5	6.03
AS2	371.7391	10.6	211	8.4	0.277	0.530	38.2	6.07
AS2	326.087	9.1	204	8.8	0.267	0.557	41.5	7.28
AS2	391.3043	9.4	210	8.1	0.287	0.591	42.0	7.28
AVE	**362.6812**	**9.7**	**205.3333**	**8.513333**	**0.234**	**0.531**	**40.3**	**6.79**
STDEV	**22.9306**	**0.6**	**3.690399**	**0.254484**	**0.042**	**0.041**	**2.8**	**0.52**
FS1	321.7391	7.3	189	7.4	0.128	0.365	37.7	5.30
FS1	323.913	7.9	173	7.9	0.154	0.339	38.0	6.80
FS1	336.9565	7.5	191	8.3	0.195	0.426	36.5	5.47
FS1	354.3478	7.9	195	8.1	0.221	0.426	33.0	5.49

FS1	302.1739	7.3	188	7.9	0.231	0.461	39.1	6.53
FS1	373.913	7.3	192	7.6	0.246	0.478	36.5	6.53
AVE	**335.5072**	**7.5**	**188**	**7.9**	**0.196**	**0.416**	**36.8**	**6.02**
STDEV	**21.60414**	**0.2**	**6.546537**	**0.3**	**0.039**	**0.046**	**1.8**	**0.56**
FS2	293.4783	7.7	194	7.1	0.102	0.409	33.9	5.68
FS2	304.3478	7.4	189	7.7	0.124	0.371	39.2	6.60
FS2	271.7391	7.8	185	7.2	0.185	0.452	37.7	5.60
FS2	336.9565	7.6	179	7.8	0.246	0.470	34.2	5.63
FS2	315.2174	7.9	186	7.4	0.246	0.478	38.0	6.07
FS2	369.5652	7.5	184	7.1	0.236	0.496	37.9	6.07
AVE	**315.2174**	**7.7**	**186.1667**	**7.383333**	**0.190**	**0.446**	**36.8**	**5.94**

STDEV	**29.05013**	**0.2**	**4.256647**	**0.25866**	**0.054**	**0.040**	**1.9**	**0.33**
MS1-1	276.087	5.3	169	6.8	0.220	0.800	47.4	6.21
MS1-1	250	5.6	175	6.5	0.265	0.800	34.8	5.54
MS1-1	282.6087	5.8	178	7.1	0.221	0.748	33.3	5.04
MS1-1	308.6957	5.5	166	6.6	0.241	0.852	29.8	5.04
MS1-1	271.7391	5.2	162	6.8	0.236	0.704	30.5	5.91
MS1-1	354.3478	5.4	168	6.9	0.251	0.878	33.2	5.91
AVE	**290.5797**	**5.5**	**169.6667**	**6.783333**	**0.239**	**0.797**	**34.8**	**5.61**
STDEV	**30.86796**	**0.2**	**4.976134**	**0.180607**	**0.015**	**0.054**	**5.4**	**0.41**
MS1-2	273.913	4.3	166	6.4	0.286	0.818	48.1	6.06

MS1-2	260.8696	4.8	169	6.1	0.344	0.817	32.4	5.73
MS1-2	256.5217	5.3	164	6.6	0.287	0.774	30.9	5.23
MS1-2	291.3043	5.4	163	6.3	0.267	0.861	27.4	5.24
MS1-2	260.8696	5.6	165	6.7	0.262	0.748	32.0	5.94
MS1-2	334.7826	5.2	162	6.4	0.267	0.913	30.5	5.94
AVE	**279.7101**	**5.1**	**164.8333**	**6.416667**	**0.285**	**0.822**	**33.5**	**5.69**
STDEV	**25.20954**	**0.4**	**2.098752**	**0.180607**	**0.028**	**0.054**	**6.7**	**0.31**
MS2-1	236.9565	3.9	160	6.2	0.517	1.722	25.1	6.30
MS2-1	217.3913	4.3	154	6.1	0.539	1.590	20.2	4.88
MS2-1	213.913	4.4	159	5.9	0.559	1.513	21.7	4.47
MS2-1	202.3913	4.1	155	6.6	0.554	1.557	21.2	4.88

MS2-1	239.1304	3.9	154	6.2	0.533	1.461	21.3	5.49
MS2-1	206.087	4.6	162	6.5	0.559	1.591	21.4	5.49
AVE	**219.3116**	**4.2**	**157.3333**	**6.25**	**0.544**	**1.572**	**21.8**	**5.25**
STDEV	**13.08297**	**0.2**	**2.91139**	**0.218763**	**0.014**	**0.075**	**1.4**	**0.55**
MS2-2	252.1739	3.7	150	6.3	0.573	1.64	27.0	6.43
MS2-2	230.4348	4.0	153	6.5	0.538	1.61	22.1	4.62
MS2-2	203.4783	4.3	155	6	0.538	1.58	21.0	4.95
MS2-2	210.4348	4.1	158	6.6	0.521	1.60	20.5	4.93
MS2-2	228.2609	4.2	153	5.8	0.554	1.50	22.0	5.59
MS2-2	213.0435	4.4	156	5.6	0.538	1.70	20.8	5.59
AVE	**222.971**	**4.1**	**154.1667**	**6.133333**	**0.54**	**1.61**	**22.20**	**5.35**

STDEV	**14.98657**	**0.2**	**2.355338**	**0.33665**	**0.01**	**0.06**	**2.06**	**0.56**

Sludge Quality Chemical Analysis

Discription	**Zn**	**Cu**	**Pb**	**Cd**	**Ni**	**Cr**	**As**
	Zn(mg/kg)	**Cu(mg/kg)**	**Pb(mg/kg)**	**Cd(mg/kg)**	**Ni(mg/kg)**	**Cr(mg/kg)**	**As(mg/kg)**
AS1	12	241.7	49.5	0.5	34.33	22.67	0.6
AS1	79	175.0	38.33	0.638	19.67	20.17	0.1
AS1	80	170.0	38.83	0.658	19.00	20.67	0.8
AS1	74	215.0	41.6	0.529	21.30	16.4	0.7
AS1	68	188.0	33.2	0.744	18.20	15.1	0.5
AS1	75	169.0	36.1	0.615	20.80	13.9	0.3
AVE	**64.66667**	**193.1**	**40**	**0.614**	**22.22**	**18.2**	**0.5**
STDEV	**23.87235**	**24.8**	**4.7**	**0.075**	**5.107**	**2.959**	**0.2**

AS2	82.3	215.0	28.3	0.416	58.83	24	0.7
AS2	68.5	150.2	34.83	0.524	18.17	10.17	0.1
AS2	68.8	168.0	34.5	0.689	17.50	11.17	0.6
AS2	71	189.0	40.3	0.493	18.90	15.8	0.6
AS2	66	195.0	36.2	0.681	15.80	14.2	0.3
AS2	62.8	210.0	38.4	0.748	19.50	13.8	0.9
AVE	**69.9**	**187.9**	**35.421667**	**0.5918333**	**24.78**	**14.8567**	**0.5**
STDEV	**5.653823**	**21.0**	**3.4885954**	**0.1115263**	**14.139**	**4.16781**	**0.2**
FS1	82.3	19.2	26.3	0.4	41.80	33.3	0.5
FS1	28	16.7	11.6	0.5	16.30	12.3	0.3
FS1	27.5	15.7	10.3	0.5	16.50	11.7	0.6
FS1	31.9	23.6	14.8	0.5	19.10	15.4	0.5
FS1	44.6	29.1	13.9	0.4	15.80	13.9	0.3
FS1	33.2	18.9	11.5	0.4	17.90	13.6	0.3
AVE	**41.25**	**20.5**	**14.733333**	**0.5**	**21.23**	**16.7**	**0.4**
STDEV	**17.78111**	**4.2**	**4.991612**	**0.1**	**8.577**	**7.0**	**0.1**

FS2	85.3	23.6	23	0.3333	38.00	27.17	0.2934507
FS2	61.167	18.7	10.2	0.552	10.70	14.17	0.8968184
FS2	51.667	18.5	11.6	0.462	10.00	14.17	0.3975007
FS2	48.2	26.6	13.6	0.428	12.80	11.9	0.6192404
FS2	55.8	21.9	10.8	0.368	11.30	14.8	0.2839939
FS2	44.2	24.3	13.9	0.345	12.90	13.6	0.5634393
AVE	**57.72233**	**22.3**	**13.85**	**0.4147167**	**15.95**	**15.9683**	**0.5090739**
STDEV	**12.45727**	**2.7**	**3.990614**	**0.0706403**	**9.181**	**4.71276**	**0.198221**
MS1-1	126	46.5	24.5	0.228	43.00	22.67	0.3566012
MS1-1	66.7	35.0	9.83	0.296	19.50	11.83	0.6573689
MS1-1	64.2	35.0	9.5	0.411	18.83	12.17	0.4321257

MS1-1	89.5	28.6	12.6	0.288	18.60	13.80	0.4365967
MS1-1	73.1	26.9	14.3	0.351	13.60	12.3	0.52469
MS1-1	83.6	31.8	11.8	0.269	16.90	12.90	0.32466
AVE	**83.85**	**34.0**	**13.755**	**0.3071667**	**21.739**	**14.28**	**0.4553404**
STDEV	**19.28884**	**5.9**	**4.6967884**	**0.0546663**	**8.984**	**3.52**	**0.1023593**
MS1-2	137.33	52.2	18	0.264	58.83	25.83	0.2747479
MS1-2	96.7	41.2	6.17	0.308	18.83	13.5	0.2613
MS1-2	63.8	36.5	5.5	0.439	18.33	13	0.3
MS1-2	88.3	39.6	8.2	0.365	15.10	15.80	0.397727
MS1-2	71.6	30.4	9.4	0.382	17.20	12.9	0.257
MS1-2	69.3	29.6	8.9	0.351	19.30	14.20	0.376
AVE	**87.83833**	**38.2**	**9.3616667**	**0.3515**	**24.600**	**15.87**	**0.3102292**
STDEV	**23.03216**	**7.0**	**3.8038342**	**0.0511545**	**14.231**	**4.22019**	**0.0517028**

MS2-1	58.333	38.7	19.1	0.412	40.00	22.67	0.16662
MS2-1	33.333	21.0	10.33	0.249	10.33	16	0.1262937
MS2-1	34.5	22.7	7.33	0.329	9.50	15	0.2289961
MS2-1	41.8	29.4	11.2	0.291	15.50	13.8	0.21373
MS2-1	33.8	21.6	9.3	0.386	13.90	17.3	0.21
MS2-1	39.2	31.6	8.1	0.352	14.60	14.80	0.1182
AVE	**40.161**	**27.5**	**10.893333**	**0.3365**	**17.306**	**16.595**	**0.1770666**
STDEV	**8.044184**	**5.9**	**3.6015777**	**0.0509531**	**9.612**	**2.70805**	**0.0399732**
MS2-2	33	25.7	20.3	0.31	26.17	17.33	0.1938
MS2-2	42.333	22.0	8.34	0.215	22.00	12	0.215661
MS2-2	42.333	23.7	6.9	0.33	23.67	12.83	0.166
MS2-2	39.6	29.5	11.9	0.459	19.50	14.6	0.15
MS2-2	32.9	21.9	9.62	0.361	21.80	15.8	0.12
MS2-2	46.2	31.6	13.8	0.284	18.60	13.5	0.15
AVE	**39.39433**	**25.7**	**11.81**	**0.3265**	**21.956**	**14.3433**	**0.1651542**

STDEV	**4.577816**	**3.4**	**4.0881956**	**0.0689405**	**2.329**	**1.67334**	**0.0300473**

APPENDIX C: ANALYSIS OF VARIANCE IN HEAVY METALS OF SLUDGE

Zinc

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
AS1	6	467	77.83333	59.76667
AS2	6	419.4	69.9	44.752

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	188.8133	1	188.8133	3.613007	0.08651	4.964603
Within Groups	522.5933	10	52.25933			
Total	711.4067	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
FS1	6	247.5	41.25	442.635

FS2	6	346.334	57.72233	217.2568

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	814.0133	1	814.0133	2.467111	0.147325	4.964603
Within Groups	3299.459	10	329.9459			
Total	4113.472	11				

Zinc

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

MS1-1	6	503.1	83.85	520.883
MS1-2	6	527.03	87.83833	742.6724

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	47.72041	1	47.72041	0.075534	0.789039	4.964603
Within Groups	6317.777	10	631.7777			
Total	6365.497	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS2-1	6	240.966	40.161	90.59245

MS2-2	6	236.366	39.39433	29.33896

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.763333	1	1.763333	0.029406	0.867266	4.964603
Within Groups	599.657	10	59.9657			
Total	601.4204	11				

Copper

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

AS1	6	1158.67	193.1117	861.3388
AS2	6	1127.17	187.8617	618.7988

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	82.6875	1	82.6875	0.111729	0.745088	4.964603
Within Groups	7400.688	10	740.0688			
Total	7483.376	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
FS1	6	123.14	20.52333	25.16291

FS2	6	133.57	22.26167	10.38962

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.065408	1	9.065408	0.509973	0.491483	4.964603
Within Groups	177.7626	10	17.77626			
Total	186.828	11				

Copper

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

MS1-1	6	203.8	33.96667	48.53067
MS1-2	6	229.44	38.24	68.72444

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	54.78413	1	54.78413	0.934443	0.356507	4.964603
Within Groups	586.2755	10	58.62755			
Total	641.0597	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS2-1	6	164.94	27.49	49.11544

MS2-2	6	154.34	25.72333	16.29971

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.363333	1	9.363333	0.286274	0.604311	4.964603
Within Groups	327.0757	10	32.70757			
Total	336.4391	11				

Lead

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

AS1	6	237.56	39.59333	31.48511
AS2	6	212.53	35.42167	17.03842

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	52.20841	1	52.20841	2.15188	0.173126	4.964603
Within Groups	242.6176	10	24.26176			
Total	294.826	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

FS1	6	88.4	14.73333	34.88267
FS2	6	83.1	13.85	22.295

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.340833	1	2.340833	0.081879	0.780607	4.964603
Within Groups	285.8883	10	28.58883			
Total	288.2292	11				

Lead

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS1-1	6	82.53	13.755	30.88375
MS1-2	6	56.17	9.361667	20.25682

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	57.90413	1	57.90413	2.264509	0.163281	4.964603
Within Groups	255.7028	10	25.57028			
Total	313.607	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS2-1	6	65.36	10.89333	18.15991

MS2-2	6	70.86	11.81	23.39868

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.520833	1	2.520833	0.121315	0.734834	4.964603
Within Groups	207.7929	10	20.77929			
Total	210.3138	11				

Cadmium

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
AS1	6	3.684	0.614	0.007927
AS2	6	3.551	0.591833	0.017413

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001474	1	0.001474	0.116344	0.740093	4.964603
Within Groups	0.126701	10	0.01267			
Total	0.128175	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

FS1	6	2.708	0.451333	0.004412
FS2	6	2.4883	0.414717	0.006986

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004022	1	0.004022	0.705776	0.420482	4.964603
Within Groups	0.056992	10	0.005699			
Total	0.061014	11				

Cadmium

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

MS1-1	6	1.843	0.307167	0.004184
MS1-2	6	2.109	0.3515	0.003664

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005896	1	0.005896	1.502774	0.24833	4.964603
Within Groups	0.039236	10	0.003924			
Total	0.045133	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

NS2-1	6	2.019	0.3365	0.003635
NS2-2	6	1.959	0.3265	0.006654

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0003	1	0.0003	0.058317	0.814056	4.964603
Within Groups	0.051443	10	0.005144			
Total	0.051743	11				

Nickle

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

AS1	6	133.297	22.21617	36.51228
AS2	6	148.6997	24.78328	279.8868

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.77026	1	19.77026	0.12497	0.731044	4.964603
Within Groups	1581.996	10	158.1996			
Total	1601.766	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
FS1	6	127.4	21.23333	102.9827

FS2	6	95.7	15.95	118.003

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	83.74083	1	83.74083	0.757885	0.404405	4.964603
Within Groups	1104.928	10	110.4928			
Total	1188.669	11				

Nickle

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

MS1-1	6	130.433	21.73883	113.0001
MS1-2	6	147.5993	24.59988	283.5105

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	24.55682	1	24.55682	0.123865	0.732184	4.964603
Within Groups	1982.553	10	198.2553			
Total	2007.11	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS2-1	6	103.833	17.3055	129.3518

MS2-2	6	131.7337	21.95562	7.595692

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	64.87076	1	64.87076	0.947382	0.353342	4.964603
Within Groups	684.7374	10	68.47374			
Total	749.6081	11				

Chromium

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

AS1	6	108.91	18.15167	12.25774
AS2	6	89.14	14.85667	24.31891

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	32.57108	1	32.57108	1.780977	0.211619	4.964603
Within Groups	182.8832	10	18.28832			
Total	215.4543	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
FS1	6	100.23	16.705	68.01891

FS2	6	95.81	15.96833	31.09414		

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.628033	1	1.628033	0.032852	0.859791	4.964603
Within Groups	495.5652	10	49.55652			
Total	497.1933	11				

Chromium

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS1-1	6	85.67	14.27833	17.38038
MS1-2	6	95.23	15.87167	24.93402

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.616133	1	7.616133	0.359978	0.561867	4.964603
Within Groups	211.572	10	21.1572			
Total	219.1881	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS2-1	6	99.57	16.595	10.26695

MS2-2	6	86.06	14.34333	3.920107

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15.21001	1	15.21001	2.144209	0.173825	4.964603
Within Groups	70.93528	10	7.093528			
Total	86.14529	11				

Arsenic

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

AS1	6	2.951911	0.491985	0.061588
AS2	6	3.286461	0.547744	0.08041

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.009327	1	0.009327	0.131368	0.724561	4.964603
Within Groups	0.709992	10	0.070999			
Total	0.719319	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
FS1	6	2.51976	0.41996	0.01582

FS2	6	3.054443	0.509074	0.055008

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.023824	1	0.023824	0.672724	0.43122	4.964603
Within Groups	0.35414	10	0.035414			
Total	0.377964	11				

Arsenic

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

MS1-1	6	2.732042	0.45534	0.014668
MS1-2	6	1.861375	0.310229	0.003742

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.063172	1	0.063172	6.862459	0.025614	4.964603
Within Groups	0.092054	10	0.009205			
Total	0.155226	11				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
MS2-1	6	1.0624	0.177067	0.002237

MS2-2	6	0.990925	0.165154	0.001264

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000426	1	0.000426	0.243201	0.632553	4.964603
Within Groups	0.017505	10	0.00175			
Total	0.017931	11				